PART III.

THE USES OF PETROLEUM AND ITS PRODUCTS.

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CHAPTER I.—THE USE OF MINERAL OILS FOR LUBRICATION.

SECTION 1.—INTRODUCTION.

Wagner's *Berichte* for 1879 contains a very full discussion of the subject of lubrication and lubricating oils. It is there remarked :

A mineral oil which, without admixture of another oil or body, as a lubricator is of unquestionable advantage. It must possess the following characteristics : 1st, it must possess the necessary consistence ; 2d, it must not harden ; 3d, it must not contain any mineral or organic acid (creosote) ; 4th, it must begin to evaporate and inflame at a high temperature (not less than 150° C.) ; 5th, it must also, at a low degree of cold, show no separation of paraffine ; 6th, it should possess only a faint odor.

He further says :

American lubricating oils are sold under the names of "Lubricating oil", "Eclipse oil," "Globe oil," "Valvoline ;" also so-called "Natural lubricating oil", which is natural West Virginia oil reduced in a vacuum, together with complex mixtures and material produced by patent processes from residuum. The lighter and clearer oils are spindle oils, those more heavy are machine oils, and the specifically heaviest in consistence and evaporating point are used for cylinders under the name of cylinder oil. The higher the specific gravity of these oils the less their fluidity and the higher their evaporating point. The specific gravity of the American lubricating oils varies from 0.865 to 0.915 at 15° C. They stiffen according to quality between —6° and —30° C., most of them between —10° and —12° C. With the exception of the West Virginia Globe oils, which are sometimes found to evaporate at 200° C., they inflame between 250° and 360° C., and boil mostly above 360° C. (*a*)

This may be taken as a fair representation of the subject as presented in the United States as well as in Germany. Although there have been those who have advocated the use of mineral lubricators for many years, it is only quite recently that any general admission of their claims to superiority has found expression. The whole question of lubrication is under discussion, and has been made the subject of a large number of memoirs during the last few years. Among these may be mentioned a very full discussion of the subject that appeared in *Le Technologiste* in 1868, two works that appeared in Germany in 1879, one by E. Donath (*b*) and the other by M. Albrecht, (*c*) and a work that was issued the same year by Professor R. H. Thurston, of the Stevens Institute of Technology, at Hoboken, New Jersey, published by Trübner & Co., of London. (*d*)

During the year 1878 the Boston Manufacturers' Mutual Fire Insurance Company commenced a general research upon oils and their relation to losses by fire, the results of which, as made public by the company, are embraced in a lecture given before the New England Cotton Manufacturers' Association at their semi-annual meeting held October 30, 1878, by Professor J. M. Ordway, of the Massachusetts Institute of Technology, (*e*) and in a paper presented by Mr. C. J. H. Woodbury to the American Association for the Advancement of Science at their meeting in Boston in 1880, and published in their proceedings for that year. From these two papers as embodying the latest results obtained, which are emphasized by the test of actual experience, I shall quote liberally.

The contract under which Professor Ordway undertook this research required that the investigation should have reference to—

1. The power of the oils to diminish friction under various pressures and at various rates of speed.
2. The tendency of the oils to oxidize while in use for lubrication, and their consequent deterioration in efficiency.
3. Their tendency to rapid oxidation when largely extended by absorbent fibrous substances, and their consequent liability to induce spontaneous combustion.

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a W. B., 1879, 1139.

b Die Prüfung der Schmiermaterialien, Ed. Donath, Leoben, 1879, Otto Protz.

c Die Prüfung von Schmierölen, M. Albrecht, Riga, 1879, G. Deubner. Hübner's Zeitsft., 1879, 67.

d Friction and Lubrication. Determination of the laws and coefficients of friction by new methods and new apparatus, by R. H. Thurston : London, 1879. Trübner & Co.

e Proceedings of the semi-annual meeting, held at Boston, October 30, 1878.

4. Their proneness to emit combustible vapors when rubbed or moderately heated, or kept long in partially-filled reservoirs.
5. Their tendency to corrode metallic bearings.
6. Their specific heat, or relative rapidity of heating and cooling when exposed to the same heating or cooling influence.
7. The relative length of time that a pint of each will last in doing a given kind of lubricating work.
8. Their relative fluidity or the thickness of layers retained between two surfaces subjected to a given pressure.
9. Their compatibility with each other when successively used on the same bearing.
10. Liability to separate into constituent parts by long standing or by freezing.
11. Their freedom from non-lubricating sedimentary matter.
12. Ease of removal from bearings after becoming thickened by floating dust or abraded particles of metal, or by accidental over-heating.
13. Their tendency to diffuse unpleasant or unwholesome odors.
14. Ease of ignition and rapidity of combustion when they are inflamed.
15. The probability of perfect uniformity in successive lots supplied by the manufacturer.
16. The possibility of securing an unlimited supply at moderate prices.
17. Suitableness for oiling wool before weaving and spinning.
18. Ease of removal from yarn or cloth in the operations of scouring.
19. Their suitableness for the manufacture of soaps.
20. Their effect on leather and wool.

Professor Ordway remarked that the report he had to make referred particularly " to certain chemical properties and the facility of oxidation of different oils ". His samples were procured directly from the mills using them, and were referred to him marked with numbers; the examination, therefore, was entirely unprejudiced. A few additional samples were procured from reliable manufacturers, and samples were imported from Paris, France. These were used in comparison. After the examination was well under way a list of names was furnished him, so that in his report he was able to give the oils the names by which they were known in commerce. Of the one hundred and eighteen oils in the list twenty-four were designated "spindle" oil, some of which were called "light" and some "heavy", fourteen as sperm, eleven as lard, nine as paraffine, five as machinery, three as olive, three as stainless, two as neat's-foot, six as wool oils, five as mixtures of paraffine and sperm, three as mixtures of paraffine and neat's-foot, and two as mixtures of sperm and spindle.

Section 2.—SPECIFIC GRAVITY.

Sections 2, 3, 4, and 5 are largely quotations from an extemporaneous lecture by Professor Ordway, which constitutes the best statement of the subject that has yet been made public.

A simple test of oils, but one of exceedingly limited value, is the specific gravity. We have determined the density of nearly all by cooling to 60° F. and weighing in a flask of known capacity. The results are as follows:

"SPINDLE" OILS.

No. 17 = 0.840	No. 21 = 0.880	No. 71 = 0.890
51 = 0.848	9 = 0.886	16 = 0.890
76 = 0.848	52 = 0.887	79 = 0.893
74 = 0.850	31 = 0.887	80 = 0.894
4 = 0.850	47 = 0.890	87 = 0.898
66 = 0.870	49 = 0.890	38 = 0.913
68 = 0.880	53 = 0.890	48 = 0.916

"SPERM" OILS.

No. 11 = 0.880	No. 44 = 0.886
26 = 0.880	75 = 0.886
28 = 0.880	77 = 0.886
32 = 0.880	35 = 0.887
54 = 0.880	40 = 0.890
56 = 0.880	34 = 0.890
58 = 0.886	36 = 0.896

These agree very closely with the true sperm oils which were procured from disinterested persons or from the shops. I got several specimens from cargoes newly arrived, taken from the casks before the vessels were unloaded, and these varied in specific gravity from 0.877 to 0.888, the latter being crude head oil, rich in spermaceti. So, if specific gravity is any indication, the oils sold as sperms are very much like genuine sperm.

"PARAFFINE" OILS.

No. 65 = 0.880	No. 27 = 0.905
59 = 0.884	45 = 0.905
85 = 0.888	69 = 0.905
63 = 0.890	2 = 0.910
43 = 0.894	

"LARD" OILS.

No. 10 =	0.914	No. IV =	0.918
19 =	0.916	VII =	0.918
13 =	0.917	VI =	0.920
81 =	0.917	Pure lard =	0.919

"STAINLESS" OILS.

No. 3 =	0.860	No. 1 =	0.890
70 =	0.874		

"NEAT'S-FOOT" OILS.

No. 50 =	0.910	No. 6 =	0.914
Pure neat's-foot =	0.920		

MACHINERY OILS.

No. 86 =	0.878	No. 61 =	0.895
39 =	0.878	24 =	0.899
33 =	0.887		

With regard to other oils than sperm, specific gravity gives no definite indication, because mineral oils may be mixed, and in that way we may get an oil of high density, yet containing oil of low specific gravity. All I can say at present is that sperm oil is very light, of about specific gravity 0.880; and lard oil should have a specific gravity of about 0.920. Lard oils are pretty thick, and petroleum oils of about the same specific gravity are also thick, and neither density nor thickness would betray an admixture. Though a great many people rely on the specific-gravity test, it is not to be depended on by itself, though it may occasionally be useful in connection with other tests.

SECTION 3.—CONTENT OF VOLATILE MATERIAL.

As to the mineral oils, we soon observed that they are some of them volatile at the ordinary temperature of the air. It is somewhat the same with petroleum oils as with water. Water evaporates at all temperatures, from the freezing point up, and so do the petroleum oils. Those that have a high boiling point do so very little, indeed; but those having a low boiling point, if left in the air in the latter part of June or July, evaporate completely in two weeks. This was rather a striking thing, as showing that it is unsafe to leave these oils exposed to the air, where there is much surface exposed, in a warm room, for we may get an explosive vapor over the whole, and if any one goes near it with a lamp there will be trouble. But this was carried further. What takes place at the ordinary summer temperature will take place more rapidly at higher temperatures; and in making our experiments we must exaggerate a little, in order to get quickly at results. Therefore we put some of these oils into an oven and observed how much they lost in twelve hours. This, I believe, is a somewhat new line of investigation, and the results are rather striking. Some of them were left for four hours, some for eight hours, and some for twelve hours; but we have finally settled upon twelve hours and 140° F., which is not a very high temperature, and which we may often have near a steam-pipe; and, in order to prevent one trouble which occurs in testing oils in this manner, we were obliged to suck up the oil in filtering paper. If you pour some oil into a watch-glass it will in time creep over the edge, and a little will be lost, and we suffered somewhat from that circumstance. We found it better to take a small watch-glass, which had been weighed carefully, and pour in oil enough to saturate a bit of paper; the paper prevents the creeping. So, in making these experiments, we took a watch-glass, put into it a piece of dry filtering paper about two-thirds as large, weighed the whole, dropped in some oil, weighed it, and put the glass into a hot oven at 140°, and observed the loss. All of the oils have been tried in this manner, and some of them give results which, to say the least, are very striking. * * * The first one was a spindle oil, at 50 cents per gallon; it lost only 1.3 per cent. The next was a spindle oil that lost 1.5 per cent., and the amount gradually increases, so that in the 43d of the table we come to an oil that lost 10 per cent. * * * And again, the percentage rises to the last, a so-called "spindle oil", at 48 cents per gallon, which lost nearly 25 per cent. What would you think of an oil which lost, by exposure to a heat which is not very great, 24.6 per cent. in twelve hours? It seemed as though all the oils which lost over 10 per cent. must be oils not to be recommended, to say the least. I think the insurance companies would say they ought to be condemned; and there is a pretty large number of such oils among those which were examined. There are twenty out of the one hundred and eighteen which lost over 10 per cent. by exposure to this moderate temperature. When the temperature is carried up to about 200° the loss in some cases was about 37 per cent. Of course it is a matter of judgment which of these should be considered safe and which should not. For my own part, I should rather not use any oil which evaporated over 5 per cent. under such circumstances. This matter has some connection with the flashing point, as one would suppose, and the flashing point is the test which has been most relied on in regard to petroleum oils. I should say, in speaking of these oils, that those that are marked sperm and lard and neat's-foot, instead of losing, gained at most 2½ per cent.—they gained all the way from nothing to 2½ per cent. All the oils of animal and vegetable origin (I mean those which were so marked) lost nothing, but gained a little. In some cases they may have been mixed with a small quantity of petroleum oil. We find that, in the case of a heavy petroleum oil mixed with a light petroleum oil, we may expose the mixture to the boiling point of the latter oil without evaporating much. The heavy oil has a power of holding back.

SECTION 4.—THE FLASHING POINT.

Now the flashing point is a matter which is determined in the case of ordinary kerosene very easily by heating the oil in a water-bath. In the case of these lubricating oils we must resort to a higher temperature and put them in an oil-bath. In this case we take a beaker, * * * hang it in oil, and expose it to a gradually raised temperature, until when we wave a small flame over the surface there will be a slight explosion. The flashing point of all the oils under examination is considerably above the boiling point of water, but some of them are not above the point to which oils might get in contact with the steam-pipe, or pretty near a pipe heated by high-pressure steam; and we all know that in factories, and in various other places, there is a possibility of oils, as well as other things, dropping upon the steam-pipe, or coming very close to the pipe itself. Of course such an oil, with such a flashing point, would be liable under such circumstances to diffuse an explosive vapor in the room. Perhaps, under any ordinary circumstances, it would not take fire, but under

some circumstances it is liable to particular danger; for it so happens in a great many of these experiments, when we want to get an accident, we cannot do it, and we have to wait until nature takes its own course. I remember some years ago trying to get an explosion with ordinary kerosene, and we found it extremely difficult, and with kerosenes which are of low flashing point it is difficult to get a condition of things in which an explosion will take place; but we know that these explosions are happening every day. With regard to the flashing points, we have tried all; we have tried, by way of comparison, a great many of those which we procured directly from the manufacturer, and which we suppose we know something about. The flashing points vary from 239° to 450° F., but on putting the figures side by side with those that represent the loss by evaporation we find the flashing point does not indicate the loss we should expect by evaporation. There is a wonderful difference. I find there is one which lost by evaporation 4.6 per cent., and it had the same flashing point as one that lost by evaporation 13.8 per cent. We find another one which lost 9.4 per cent., and yet it flashed at the same heat as one that lost 24.6 per cent. by evaporation. This would seem to show that the flashing point is not to be so much relied upon. I place a good deal more reliance on the other experiments, to long exposure in contact with the air at a given temperature; and the flashing point I should set down as one of the things that may give uncertain results. If any oil has a low flashing point it ought to be rejected; but, at the same time, an oil bearing a high flashing point may be mixed with a certain amount of a lighter oil, which will freely evaporate when exposed to the air more rapidly than another oil with a low flashing point.

SECTION 5.—SPONTANEOUS COMBUSTION.

Of course those oils, which, on being exposed twelve hours to a high temperature (140°) gain something, gain it from the air on oxidation; and they are found to be, as a general thing, either of animal or vegetable origin. * * * I believe the sperms gain rather more than the lard or neat's-foot. Of course this oxidation is a matter which is of considerable importance with reference to spontaneous combustion; and we have attempted to make experiments on spontaneous combustion, which is a matter depending on the oxidation of oil when spread out over a great surface. We imbibe fibers with the oil in such a way that they are not dripping with the oil, but simply dampened with it, and then expose them to hot air, and in the course of time, whether the fiber is cotton, or jute, or wool—in time they will all take fire when we have used an animal or vegetable oil. It is rather difficult to carry out these experiments on a small scale, because we use only a handful; but when you have a large basketful of waste there is no difficulty. In order to make up for the tendency to loss it was necessary, of course, to heat the soaked waste to a temperature which might be considered rather high. We have made experiments at 140° F., and we have made them at 190°, and we have made them above the boiling point of water; in all cases it was below the igniting point of the oils. To make experiments on spontaneous combustion we took a given weight of cotton-waste, about a handful, and imbibed it with its own weight of the oil to be tried; for it is quite an important matter that the experiments should be made with the same quantity of oil, and that the oil should be spread out in the same way throughout. When the waste is imbibed with its own weight it does not appear very greasy. It is not in a dripping condition, but in a state where it is still ready to imbibe. It is said by those who have made such experiments in Europe that equal weights of cotton and oil are the best; and I should suppose that to be the case, as then the air has the freest access to a large surface of the oil. The cotton, of course, is only matter which serves to spread out the oil, and to act as a non-conductor to prevent the heat from being radiated. We made experiments on spontaneous combustion at 200° and at 220°, but not as many of them as could be desired.

One of the important things was to determine the accuracy of the trials made in Europe a few years ago. There were some experiments, published in the *Bulletin of the Industrial Society of Mulhouse*, in 1875 and 1876, experiments made by Mr. Coleman, of Glasgow, and by Dolfus, in Alsace. The experiments of these gentlemen show that when an animal or a vegetable oil is mixed with a small percentage of petroleum oil the tendency to spontaneous combustion is diminished very much, and if with a large quantity of mineral oil the spontaneous combustion refuses to take place. There is, however, in this latter case an oxidation. They found in their experiments, when they took an oil which consisted of thirty parts of petroleum and seventy parts of an animal or vegetable oil, that the oil would heat up when exposed to steam heat, but when it arrived at a certain point it would go down. There is an oxidation, therefore, in such a case; but the petroleum prevents its oxidizing so fast as to allow the heat to accumulate and set the mass on fire. This, of course, is a very important point; and it was important to determine whether their results apply to the oils we have as well as those commonly met with in Europe. They use more vegetable oil, whereas sperm oil does not seem to be so common there as it is here. They found that all the oils tried by themselves would undergo spontaneous combustion, but when they contained from 30 to 50 per cent. of a mineral oil spontaneous combustion would no longer take place under the circumstances to which they exposed them.

We have made experiments with cotton-waste and cottonseed oil mixed with petroleum oil, and have found that cottonseed oil mixed to the amount of 25 per cent. with 75 per cent of petroleum oil will take fire spontaneously; so it seems that although spontaneous combustion is retarded in a great degree, it is not entirely prevented, even by a pretty large admixture of petroleum oil in the case of such oils as cottonseed and linseed, which are peculiarly prone to oxidation. When we came to take lard oil a careful experiment was made, which showed that 33 per cent. of petroleum oil (for this purpose what is commonly called spindle oil was taken) mixed with 67 per cent. of lard oil would not undergo spontaneous combustion at the temperature at which the experiment was made; whereas with 32 per cent. it did undergo spontaneous combustion. It would be very desirable to carry out these experiments to that degree of nicety in all cases, but you can easily see, when we are obliged to expose these oils to long-continued heat, and have an apparatus which must be isolated from the wood work around, we cannot have a great many of them going on at a time, and an experiment lasts from six to eight hours. Generally it takes to finish up one of these experiments on spontaneous combustion six hours. Some of them will take fire in three hours, but the heat does not accumulate enough with most until they have been kept in the oven for five or six hours. A great deal remains to be done in this line. * * * We all know cottonseed oil is one of those oils we have to fear, and it happens to be one of those whose spontaneous combustion cannot be prevented by a slight admixture of petroleum oil. But the experiments of Dolfus (a) and Coleman (b) were correct, it seems. We had no reason to doubt they were correct, but the experiments we made were made at a little higher temperature; and although the oil, mixed in the proportion of 70 parts of oil and 30 of petroleum oil, may not take fire spontaneously when the temperature is maintained at 110° F., yet it may when it is maintained at 190° F.; and, of course, cotton-waste is liable to be exposed sometimes to a steam heat, and a steam heat may range up to 300° F., so that even when the oils are mixed with petroleum oil there is danger. Still, it is a fact that the admixture of even 10 per cent. of one of the heavy petroleum oils does diminish very much the tendency to oxidation or to spontaneous combustion, and that is a fact, of course, of immense importance. * * * We have tried the different animal and vegetable oils, some of them mixed with larger or smaller proportions of petroleum, but that investigation is still unfinished.

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a Bull. Soc. Ind. de Mulhouse, 1876.   *b* C. N., xxx, 147; W. B., 1871, 1874, 1875.

SECTION 6.—FLUIDITY.

There is another matter which might be of some importance, but we have not been able to deduce from our trials any data of practical value; that is, the relative fluidity of the oils. There is a wonderful difference in this respect, and we found all the lighter oils, that is, the lighter paraffine and spindle oils, are very much more fluid than the sperms of corresponding specific gravity. The specific gravity and fluidity have little relation to each other; there is some, but no exact correspondence. (a) The mode of experiment for this purpose is to take a small pipette, of which the globe holds about a cubic inch. The globe is filled by sucking the oil up to the neck, and the liquid is then allowed to flow out through a very small aperture thirty-seven thousandths of an inch in diameter, and the time of flow is noted. The experiments must be made in a room which is kept at a uniform temperature.

In this way ran out—

	Min.	Sec.
Sperm	3	43
Linseed	5	42
Poppy	6	49
Cottonseed	7	31
Sesame	8	14
Lard	9	24
Olive (mere *goutte*)	9	26
Neat's-foot	9	29
Rape	9	55
Navette	10	9
Colza	10	0

Castor, over two hours.

There is another point which we would like to draw some deductions from if we could, but so far we have not found any particular law. If we immerse wicks in these oils, or filtering paper, which amounts to the same thing, of course, the distance which the oils will ascend or be carried up by capillary attraction is a matter depending on the fluidity of the oil, and this does not seem to have any exact relation to the flowing out through a small aperture. It is contrary to what I should have expected. * * *

SECTION 7.—CHEMICAL TESTS.

There have been various chemical tests proposed from time to time for oils, but in our investigation we were obliged to go on the supposition that almost nothing had been done, from the simple fact that the oils which have been experimented on in former times, in France particularly, have been mixed, and oils which are no longer in use. (b) We have experiments relating to the adulterations of olive oil and linseed oil and rape, but those adulterations are out of fashion, and they used certain tests which give comparative indications only; there is nothing absolute about them. One of these tests is nitrate of mercury, which acts simply from containing in solution a certain quantity of nitrous acid. Another test is strong oil of vitriol, and another is caustic soda, and another is chloride of zinc. We can get very little aid or comfort from these old experiments. The nitrate of mercury test is of some trouble to carry out. And finally a very much better fluid has been invented by Jules Roth. He used a fluid which absorbs nitrous acid in considerably larger quantities than nitrate of mercury, and which could be kept for a considerable length of time. It is made by passing nitrous fumes, formed by acting on lumps of iron with nitric acid, into sulphuric acid at 46° B. The charge up of the acid takes some eight, ten, or twelve days. It is a slow operation, but when it is well carried out you get a greenish or bluish liquid, which has a wonderful effect on some oils, and although there is nothing absolute to be learned by this, it gives comparative indications of great value. It seems that all those oils that oxidize readily are not effected by this test, whereas those that keep better, that are not so prone to grow rancid, will thicken and become quite hard when tested with it.

In making these experiments we generally take a small wine glass and put in a little of the liquid and about the same amount of the oil that is to be examined, and then they are whipped together and allowed to stand for some time. If the oil is a good one, one that doesn't oxidize readily, we shall find that the product is very stiff; even if you turn it upside down very little liquid will come out, and it is more like wax or tallow than the original oil. The sample I have in my hand is olive; this is good olive oil, and you may see from the appearance of this that I find considerable difficulty in pushing a rod into it; it is as stiff as beef tallow. Good olive oil will do this, but if adulterated with even 1 per cent. of these other oils the product is softer. Olive oil hardens very readily indeed, and good lard oil also hardens with promptness. This is a specimen of lard oil; I can push the rod through this without very much trouble. Here is one that is mixed with 5 per cent. of petroleum. You will observe on comparing these two that the petroleum oil has undergone such a change that it is colored yellow. The color indicates something. Here the lard oil is thoroughly white and will remain so; whereas if there is an admixture of petroleum oil, however little, it will be pretty sure to turn yellow, and the product is softer than the other. I have here another which is a mixture of cottonseed and olive oil. Here you see a perfectly fluid oil; there is a little thickening from the acid below, but it still remains in a fluid condition; and this contains one-third of cottonseed and two-thirds of olive. By taking great pains we can distinguish 5 per cent. of admixture very well.

These, of course, for illustration, have been exaggerated a little bit. That is, I have taken larger quantities than would be necessary if I were going to make an exact trial to determine how much can be used without interfering with the fluidity. I have here a mixture of lard oil with 20 per cent. of cottonseed that has thickened, but not very much. Now, when we take this same test and apply it to rape-seed oil, it remains perfectly fluid. Of course rape-seed oil, were it mixed with olive or lard oil, would diminish the consistency of the product very much indeed. Here is neat's-foot oil. One would suppose it would be very much like lard, but it is not; it remains fluid without the oxidation surface or crust. This hardening usually takes place in the course of six or eight hours. The best way is to let them stand and watch them and see at what rate the hardening goes on. If you find one hardens in four hours, you will find that it is a pretty good olive or lard oil; if it is six hours, it may be mixed; if it is eight hours, it is more likely to be mixed, and sometimes it is necessary

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a An oil distilled from California malthas of a specific gravity of 16° B. flowed like an essential oil.—S. F. P.

b This statement of Professor Ordway explains why the investigations that have been made prior to the last few years are of so little value at present.

to let them stand until the next day; then we have a little hardening. (a) In the case of petroleum oils we have a very peculiar effect. Here is one of them : it has become very highly colored; the petroleum oil itself becomes colored, and the fluid below becomes colored, and we can distinguish it by this discoloration. And there is another test, too. Whenever you have whipped up a petroleum oil with this liquid, and have let it stand for some hours, ten or twelve hours, there will be a matter like this sticking to the rod; a waxy, sticky substance, something that is neither oil nor wax; it is not paraffine; precisely what it is I don't know; it is a matter which still remains to be investigated. All of the petroleum oils that we have examined, without exception, I think contain more or less of the matter which gives this precipitate, and the heavier the oil the greater the amount of the precipitate; but even the light spindle oils and kerosene itself will show a definite coating on the rod or else a definite coating on the surface of the liquid itself. We have here a test in Roth's liquid, which is a very good indication of something. We cannot say positively when we have an oil hardened in this way what the oil is, but we can say what it is not, and that sometimes is a very important thing. If it purports to be so and so, we can see whether it is so and so or something else.   *   *   *

Mr. ATKINSON. I should like to put one question at this point to Professor Ordway that I think is important. I believe you have reached the conclusion in respect to the amount of that gummy substance in a petroleum oil that it largely depends on the point to which the distillation has been carried, and that the double distilled and refined oils contained the least?   *   *   *

Professor ORDWAY. That is so ; there are specimens here to show that. There is one here which has been distilled once, and another which has been distilled twice. It cannot be seen across the room ; but if any one examined these closely he will see that the precipitate on the surface of the liquid below is greater in one case than in the other, and the discoloration is about the same.

Mr. ATKINSON. I think I am also right in asking you whether or not that is not the substance which probably causes the staining of the cloth and the varnishing of the windows and of the polished parts of the machinery?

Professor ORDWAY. It may be that substance. I should not be willing to say positively it is until we have made further experiments. This is a subject which has not been investigated, I believe; and it is quite important that we should spend time and find out what it is. It is something objectionable, it seems to me. It is said by some of the manufacturers of paraffine oil that a little of this in an oil does no harm ; but that is not a point we should take for granted. While it may not do any harm in respect to lubrication, it may have something to do with the staining. Here is a substance which is got on oxidation. It has kept on turning brown, and that brownness may go on to a certain point where it will effect a permanent stain on the cloth. I am reasoning theoretically, but I think there are good grounds for saying, if an article of this sort is allowed to stain cotton or wool, and allowed to remain for some time, this substance will become precipitated and go on oxidizing and make a permanent defect. This is a point which it is very desirable to have further light on ; and we can only get at it by a long series of trials, for the amount which we get of this is not very great. This is a body which is carried forward by the vapor; for all vapors have a great carrying power, and although the boiling point of this substance is probably very high when oils are distilled, a little is carried forward even by kerosene itself.

There are other chemical tests which so far we haven't had the time really to carry out.   *   *   *   Among other things it would be desirable to find out something by saponification, and experiments in saponification are slow. We generally have to boil for ten, twelve, or even fifteen hours; and, when you undertake to saponify a dozen oils, you see it would take a good many individuals to carry on those experiments in a short time.   *   *   *   There has one thing turned up which I was not aware of before : that sperm oil does not saponify readily. We have taken pure sperm oil, and we find it is exceedingly difficult to saponify more than 47 or 48 per cent. of it. I mention this because some might be tempted, after making an experiment of this sort on an oil of an unknown origin, to think it was not a sperm oil. This peculiarity arises, I suppose, from a difference in the composition of sperm from other oils. Precisely what it is I don't know, because there has been very little written on the subject of sperm oil; and it opens up, unexpectedly to me, a new field for investigation, and I think the character and quality of sperm oil ought to be investigated by scientific men. Here is this fact which is admitted by a great many people: that sperm oil, of all the animal and vegetable oils, is the best lubricator. It is not because it contains more oleine, but it is something in the character of the oleine. After we have eliminated all the spermaceti, we get a peculiar oil which is different from the other animal oils, but I think it is *sui generis*. We have saponified a great many of the oils. Those which saponify with most ease are lard oils. Neat's-foot saponifies pretty readily. When we take those that are mixed with petroleum, we can saponify all the way from 5 per cent. up, according to the proportion of the petroleum. I am not able at present to give any particular directions about saponification, for this is a matter which requires to be understood so as to present it to people in ordinary life, and I think it can be made a very good test of the character of oils, but in order to do it there must be a great deal of experiment.   *   *   *   At present all I can say is, a good many of the oils we have examined saponify very readily ; and these turn out to be, according to the descriptive lists, lard oil or something similar to lard oil. There are a good many of them which didn't saponify at all ; and, on reference to descriptive lists, they are found to be paraffines.

When the oils are poured on a brass plate and allowed to run slowly down for a length of time some of them get quite green ; they color the brass; they are decidedly acid in their character. In looking over these results I noticed that all the oils which are acid are either sperm or neat's-foot, and all of the sperm—I mean all those that purport to be sperm and neat's-foot—are acid in their character, whereas the other (the petroleum oils) don't show any acid reaction. (b)

Following the close of Professor Ordway's remarks, Mr. Edward Atkinson and the professor engaged in a discussion of the practical value of the flashing and evaporation tests as applied to lubricating oils. The following is a summary of their conclusions : The flashing point is no indication of the lubricating power of an oil, but has an important bearing on insurance. No oil should be used about a manufacturing establishment that " can diffuse from the bearings an explosive vapor into the atmosphere". While there are some manufacturers of oils that can be depended upon, it is found that oils purporting to come from some others differ widely in quality. Several specimens of oil having the same name differ greatly in flashing point and other characteristics, yet the price remained about the same, and was evidently intended for the same article. While it appears to be difficult for unskillful manufacturers to prepare oils of uniform quality, there are others whose product varies but slightly, and it was somewhat remarkable that some of them having the low flashing point were high-priced, while others having a low flashing point were

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a I have quoted Professor Ordway fully, although the text does not relate to petroleum, because of the great value of his experiments.

b This long quotation, reported from an extemporaneous lecture, and consequently somewhat diffuse in style, has been introduced here as the best statement of the subject treated that has yet been made public.—S. F. P.

among the lowest-priced oils on the market. It was found that many of the best managed corporations, ignorant of their true character, were using oils with a high flashing point. But, in addition to the element of safety from the use of these oils, which rapidly evaporate, is found the question of profit.

The cost of oil per 1,000 pounds of cloth of about No. 33 yarn, in mills in which there is no reason in the character or kind of machinery for a variation exceeding 25 per cent., appears to vary from .68 cents to $2 58 per thousand, while the quantity used varies from 1.03 to 3.36 gallons per 1,000 pounds. It does not appear that this variation has any particular connection with the price of the oil. * * * But since we have begun to compare the results of the tests of evaporation and flashing point a very distinct relation of these tests to the actual cost of oil per 1,000 pounds of cloth is foreshadowed, and if we can establish this rule a great point will have been gained.

The following striking illustration is given of the probable effects of the use of a lubricating oil from which the volatile material had not been completely removed: (a) The fire caught in the basement and communicated with striking rapidity with a weaving-room up one flight of stairs in which woolen fabrics were being woven and in which there were "no peculiarly combustible conditions". The flames flashed instantly from one end of the room to the other, striking like a stroke of lightning the gas-meter, placed on a shelf some six or eight feet from the floor at the farther end of the room, melting all the solder, and dropping the connecting pipes from the meter, while a towel that was hanging 2 feet under it was not scorched. The wool oil and the lubricating oil being both examined, the former was found to be pure lard oil, while the latter was one which had evaporated from the evaporation plate completely in five days. There was an oil on those bearings in that woolen weaving-room that did evaporate with extreme rapidity; there was a fire that flashed through the room giving the appearance of flames. Of course evaporation is waste, and is not only injurious, but unprofitable.

The following paper, upon the "Separation of Hydrocarbon Oils from Fat Oils", by Alfred H. Allen, is given here as the latest and best English contribution to the literature of this subject: (b)

The extensive production of various hydrocarbon oils suitable for lubricating purposes, together with their low price, has resulted in their being largely employed for the adulteration of animal and vegetable oils. The hydrocarbons most commonly employed for such purposes are:

1. Oils produced by the distillation of petroleum and bituminous shale, having a density usually ranging between 0.870 and 0.915.

2. Oils produced by the distillation of common rosin, having a density of 0.965 and upward.

3. Neutral coal-oil, being the portion of the products of distillation of coal-tar boiling at about 200° C., and freed from phenols by treatment with soda.

4. Solid paraffine, used for the adulteration of beeswax and spermaceti, and employed in admixture with stearic acid for making candles.

The methods for the detection of hydrocarbon oils in fat oils are based on the density of the sample, the lowered flashing and boiling points, the fluorescent characters of the oils of the first two classes, and the incomplete saponification of the oil by alkalies. The taste of the oil and its odor on heating are also useful indications.

If undoubtedly fluorescent, an oil certainly contains a mixture of some hydrocarbon, but the converse is not strictly true, as the fluorescence of some varieties of mineral oil can be destroyed by chemical treatment, and in other cases fluorescence is wholly wanting. Still, by far the greater number of hydrocarbon oils employed for lubricating purposes are strongly fluorescent, and the remainder usually become so on treatment with an equal measure of strong sulphuric acid.

If strongly marked, the fluorescence of a hydrocarbon oil may be observed in presence of a very large proportion of fixed oil, but if any doubt exists the hydrocarbon oil may be isolated. As a rule, the fluorescence may be seen by holding a test-tube filled with the oil in a vertical position in front of a window, when a bluish "bloom" will be perceived on looking at the sides of the test-tube from above. A better method is to lay a glass rod, previously dipped in the oil, down on a table in front of a window, so that the oily end of the rod shall project over the edge and be seen against the dark background of the floor. Another excellent plan is to make a thick streak of the oil on a piece of black marble or glass smoked at the back, and to place the streaked surface in a horizontal point in front of and at right angles to a well-lighted window. (c) Examined in this manner, a very slight fluorescence is readily perceptible. If at all turbid, the oil should be filtered before applying the test, as the reflection of light from minute particles is apt to be mistaken for true fluorescence. In some cases it is desirable to dilute the oil with ether and examine the resultant liquid for fluorescence. An exceedingly small amount of mineral oil suffices to impart a strong blue fluorescence to ether.

The quantitative analysis of mixtures of fat oils with hydrocarbon oils has till recently been very uncertain, the published methods professing to solve the problem being for the most part of very limited applicability, and in some cases wholly untrustworthy.

When the hydrocarbon oil in admixture happens to be of comparatively low boiling point, it may often be driven off by exposing the sample to a temperature of about 150° C., but the estimation thus effected is generally too low, and often quite untrustworthy.

When it is merely desired to estimate approximately the proportion of hydrocarbon oil present, and not to isolate it or examine its exact character, Kœttstorfer's titration process may be used, as suggested by Messrs. Stoddart. But the best and most accurate method of detecting hydrocarbon oils in, and quantitatively separating them from, fat oils, is to saponify the sample, and then agitate the aqueous solution of the soap with ether. (d) On separating the ethereal layer and evaporating it at or below a steam heat the hydrocarbon oil is recovered in a state of purity.

Either caustic potash or soda may be employed for the saponification, but the former alkali is preferable, owing to its greater solubility in alcohol and the more fusible character of the soaps formed. A convenient proportion to work with consists of 5 grms. of the sample of oil and 25 c. c. of a solution of caustic potash in methylated spirit, containing about 80 grms. of KHO per liter. Complete saponification

a In this case the volatile oils appeared to constitute the bulk of the lubricator used.

b Oil and Drug News, October 18, 1881. Read at the 1881 meeting of the British Association.

c "Either of these plans is infinitely superior to the polished tin-plate usually recommended. In short, the background should be black, not white."

d "According to my experience, treatment of the dry soap with ether, petroleum spirit, or other solvent is liable to cause error from solution of the soap itself, if much hydrocarbon oil be present."

may usually be effected by boiling down the mixture in a porcelain dish, with frequent stirring, until it froths strongly. In the case of butter, cod-liver oil, and other fats which undergo saponification with difficulty, it is preferable to precede this treatment by digestion of the mixture for half an hour at 100° C. in a closed bottle. After evaporating off the alcohol, the soap is dissolved in water, brought to a volume of 70 to 80 c. c., and agitated with ether. The ethereal solution is separated, washed with a little water, and carefully evaporated The agitation with ether must be repeated several times to effect a complete extraction of the hydrocarbon oil from the soap solution.

The foregoing process has been proved to be accurate on numerous mixtures of fat oils with the hydrocarbon oils. The results obtained are correct to within about 1 per cent. in all ordinary cases. In cases where extreme accuracy is desired, it is necessary to remember that most, if not all, animal and vegetable oils contain traces of matter wholly unacted on by alkalies. In certain cases, as butter and cod-liver oil, this consists largely of cholesterin, $C_{26}H_{44}O$. (a)   The proportion of unsaponifiable matter soluble in ether, which is naturally present in fixed oils and fats, rarely exceeds 1½ per cent., and is usually much less. Sperm oil, however, constitutes an exception, yielding by the process about 40 per cent. of matter soluble in ether. (b)   This peculiarity has no practical effect on the applicability of the process, as sperm oil, being the most valuable of commercial fixed oils, is never present without due acknowledgment of the fact. Spermaceti and the other waxes yield, after saponification, large percentages of matter to ether, and hence the process is not available for the determination of paraffine wax in admixture with these bodies, though it gives accurate results with the mixtures of paraffine and stearic acid so largely employed for making candles. The following figures, obtained in my laboratory by the analysis of substances of known purity and of mixtures of known composition, show the accuracy of which the process is capable., The process was in each case on about 5 grms. of the sample in the manner already described.

The results are expressed in percentages:

Composition of substances taken.				Unsaponifiable matter found.
Fat oil.	Results.	Hydrocarbon oil.	Results.	
	Per cent.		Per cent.	Per cent.
Olive	40	Shale oil	60	58. 03
Olive	80	Shale oil	20	19. 37
Olive	40	Rosin oil	60	59. 42
Olive	80	Rosin oil	20	19. 61
Rape	86	Shale oil	16	15. 95
Cottonseed	60	Rosin oil	40	39. 74
Linseed	60	Rosin oil	40	39. 32
Castor	60	Rosin oil	40	38. 88
Cod-liver	70	Rosin oil	30	30. 80
Cottonseed	48	Coal-tar oil	52	52. 60
Lard	60	Paraffine wax	40	39. 54
Lard	20	Paraffine wax	80	80. 09
Olive	100			*1. 14
Rape	100			*1. 00
Castor	100			0. 71
Cod-liver	100			1. 82
Palm	100			0. 54
Butter fat	100			0. 46
Sperm	100			41. 49
Spermaceti	100			49. 68
Japan wax	100			1. 14
Lard	100			*0. 23
Cacoa butter	100			0. 22

* These experiments were not made strictly by the same process as the majority.

The following table indicates the general behavior of the constituents of complex fats, oils, and waxes when the aqueous solution of the saponified substance is shaken with ether:

Dissolved by the ether.
Hydrocarbon oils; including—
    Shale and petroleum oils.
    Rosin oil.
    Coal-tar oil.
    Paraffine wax and ozokerite.
    Vaseline.
Neutral rosins.
Unsaponified fat or oil.
Unsaponifiable matter; as cholesterin.
Spermyl alcohol; from sperm oil.
Cetyl alcohol; from spermaceti.
Myricyl alcohol; from beeswax.

Remaining in the aqueous liquid.
Fatty acids.   ⎫
                          ⎪
Resin acids.   ⎬ In combination with the alkalies used.
                          ⎪
Carbolic and   ⎪
c Cresylic acids.   ⎭

Glycerol (glycerine).

The hydrocarbon oil having been duly isolated by saponifying the sample and agitating the solution of the resultant soap with ether, its nature may be ascertained by observing its density, taste and smell, behavior with acids, etc.

a "The process affords a very rapid and simple means of isolating cholesterin. Thus, on dissolving the traces of unsaponifiable matter left by butter in a little hot alcohol, and allowing the liquid to cool, abundant crystals are deposited, which may be identified as cholesterin by their microscopic and chemical characters. A sample of butterine gave no cholesterin."

b "I am investigating this interesting fact, and have obtained full confirmation of Chevreul's observation that sperm oil when saponified yields a peculiar solid alcohol instead of glycerine. It is distinct from cetyl alcohol, and distills, apparently without decomposition, at a very high temperature."

c "In a previous research I found that carbolic and creslyic acids were wholly removed from their ethereal solutions by agitation with caustic soda."

SECTION 8.—PRACTICAL RESULTS OF THE INVESTIGATIONS OF PROFESSOR ORDWAY.

In a circular issued in 1880 Mr. Edward Atkinson treats the subject of oil as follows:

In the two years and little more that have elapsed since the question was taken up for the mere purpose of abating some of the dangers of fire the following changes have occurred. * * * In 1878 a request made for information was responded to by the managers of one hundred mills, who gave the quantity and price of the oils used for lubrication, the pounds of cotton goods manufactured in preceding periods of six or twelve months, and other data. These returns were compiled, and it appeared that in fifty-five mills, operated on about the same fabric, and among which there was no good reason for a variation of over 20 per cent. either in cost or quantity of oil used, the actual variation was about 350 per cent. It will also be remembered that a large portion of the waste of oil consisted in evaporation, whereby the atmosphere was sometimes charged with combustible vapors, by which some fires that might otherwise have been easily subdued were made very dangerous. It was for the special purpose of discovering the facts in this particular matter and applying the remedy that the inquest was first entered upon.

It is a great satisfaction to be able to state that within the first year after we agitated this subject a settlement was made in a patent lawsuit, the principal manufacturers of lubricating oil agreeing to pay a royalty for the right to use superheated steam in their preparation, and by that or other methods a great change for the better was made. The volatile and dangerous oils do not now appear to be upon the market, or, at any rate, are apparently no longer offered to members of our company to any extent. They are very easily detected and avoided; and we still stand ready to examine any and all samples, and to inform all our members of the names of dangerous oils, and to warn them against the vendors.

Very soon after the change in the process of manufacture a sharp competition ensued in the sale of good oil, and a considerable reduction of prices followed.

The change in practice has been very great during the last two years. We have lately called upon the same mills that gave us data in 1878 to make a similar return for six or twelve months ending in 1880, and have received answers from 78.

From the 78 returns we get the following results:

The product of cotton goods in these mills for a period averaging $8\frac{1}{3}$ months prior to June 30, 1878, was 102,874,748 pounds, or 12,653,720 pounds per month. For a period averaging $8\frac{1}{3}$ months prior to June 30, 1880, it was 110,166,595 pounds, or 13,550,620 pounds per month. Increase in product, 7.09 per cent. The quantity of oil used in the first period was 176,766 gallons, or 1.72 gallons to each 10,000 pounds cloth. In the second period, 173,481 gallons, or 1.57 gallons to each 10,000 pounds cloth. Decrease in the consumption of oil, 8.72 per cent. The cost of oil and grease for lubrication in the first period was $103,162 25, or $10 03 to each 10,000 pounds cloth. In the second period, $73,482 71, or $6 67 to each 10,000 pounds cloth. Decrease in the cost of lubrication, 33 per cent.

If the cost of lubrication had been $10 03 for each 10,000 pounds in 1880, the gross sum would have been. $110,497 19
The actual cost was 73,482 71

Difference for $8\frac{1}{3}$ months 37,014 48
or, for 12 months, in round figures... 55,000 00

The above seventy-eight mills represent an annual consumption of 400,000 bales of cotton, which constitutes about 30 per cent. of the consumption of the cotton factories insured in this or in other mutual companies. If the decrease of cost in these mills represents an average of the whole, the lubrication of machinery in cotton-mills insured by us costs $180,000 less annually than it did at the time this investigation was entered upon. The change has been computed first on fifty-three, then on sixty-five, and last on seventy-eight mills, with substantially uniform results. We may therefore infer a general rule.

Of course we cannot claim all this saving as the direct result of our work, because there has been a great decline in the prices of oils, ranging from 10 to 40 per cent., except so far as that reduction may be attributed to this investigation. One of the largest dealers to whom these figures have been submitted attributes two-fifths to the reduction of price, and the remainder to the saving of waste and to the more general use of a uniform quality of fine mineral, or so-called paraffine oil, at a substantially uniform range of prices, in place of a considerable use of mixed oils under fancy names, and at all sorts of prices. In comparing particular cases, we find this view confirmed; but, if we may not assume so much of the savings as would amount to three-fifths, or $100,000 a year, yet we may fairly claim, as the direct result of changes made in consequence of this investigation, a sum equal to all the losses and expenses of this company for the two years that have elapsed since our work began to have an influence, especially an influence on the manufacture of oil.

SECTION 9.—DETERMINATION OF THE VALUE OF LUBRICATING OILS BY MECHANICAL TESTS.

During the discussion that followed the lecture given by Professor Ordway, previously quoted, Mr. Edward Atkinson remarked as follows:

I will now say, also, that inasmuch as we have obtained three frictional machines—two American and one English—all of which may prove unsuitable, it has occurred to us to establish the rule of lubricating power on spinning-frames actually in operation by the application of thermometers to every spindle. * * * Three small frames have been provided, which are to be started and operated with full bobbins, and with thermometers applied to the steps and bolsters; we will then use the different oils upon them, and see if we can establish by the ratio of heat evolved any rule as to the lubricating power of each oil. In a rough-and-ready way we have applied that test to the shaft of the elevator in our office building, and there are several results that have been obtained that prove that there is a very simple method available to almost anybody. I caused some thermometers to be prepared, and mounted them in copper cartridges filled with water, and then had the journal-box of the shaft bored, and one of these thermometers placed so as to rest against the shaft as it is in use, and then hung another one in precisely the same way alongside.

The first shaft that we tried was belted both ways, and had no serious bearing upon its journal. The second shaft is the principal shaft operating about four hundred turns, and working the elevator with the belt bearing down upon it. Under the first oil we tried the shaft heated about 30° F. In hot days, when the atmosphere of that room was at 100°, the shaft showed 128° to 130°. We then tried some light spindle oil which we didn't think fit for a heavy-bearing oil, yet that carried the heat down about 10°. We then tried some plumbago mixed with paraffine by Mr. Toppan; it was very difficult to get it on, but that worked it 10° cooler than the first oil. We then tried another oil, which heated so rapidly that we took it off at once; we didn't dare to run it. We then tried another and got down to 17° above the temperature of the room. It is a very simple matter; * * * and I think it will prove a good way for testing oils on a bad bearing, which almost every man has somewhere in his mill.

The management of the further mechanical tests was placed in the hands of Mr. C. J. H. Woodbury, of Boston, who embodied his results in a paper read before the annual meetings of the American Society of Mechanical Engineers and the American Association for the Advancement of Science for 1880. The following abstract of this paper, which presents results which "have been accepted as a long step in advance of anything ever attained before", is introduced here with the permission of the author: (a)

The resistance existing between bodies of fixed matter, moving with different velocities or directions, presents itself in the form of a passive force, which results in the diminution or the destruction of apparent motion. Modern science has demonstrated that this destruction is only apparent, being merely the conversion of the force of the moving body into the oscillation of the resisting obstacle, or into that molecular vibration which is recognized as heat. Direct friction refers to the case where the two bodies are in actual contact, and mediate friction where a film of lubricant is interposed between the surfaces, and it is this which applies to nearly every motion in mechanics where bodies slide upon each other. The coefficient of friction is the relation which the pressure upon moving surfaces bears to resistance. * * * In this report of my work upon the measurement of friction of lubricating oils I shall restrict myself to a description of the apparatus designed especially for the purpose, the method of its use, and the results obtained with a number of oils in our market which are used for lubricating spindles. Previous trials of nine different oil-testing machines in use showed that none of them could yield consistent duplicate results in furnishing the coefficient of friction. The operation of these machines, by their failure to obtain correct data, adduced certain negative evidence, which established positive conditions as indispensable in the construction of a machine capable of measuring the friction of oils. The following circumstances must be known or preserved constant: Temperature, velocity, pressure, area of the frictional surfaces, thickness of the film of oil between the surfaces, and the mechanical effect of the friction. In addition to the foregoing conditions, the radiation of the heat generated by friction must be reduced to a minimum, and the arrangement of the frictional surfaces must be of such a nature that no oil can escape until subjected to attrition. To measure the frictional resistance at the instant of a given temperature, and at a time when both temperature and friction are varying, requires a dynamometer which is instantaneous and automatic in its action.

The apparatus consists of an iron frame supporting an upright shaft, surmounted by an annular disc made of hardened tool steel. Upon the steel disc rests one of hard bronze (composed of the following alloy: copper thirty-two parts, lead two parts, tin two parts, zinc one part) in the form of a cylindrical box. Water is fed in at one side, and a diaphragm extending nearly across the interior produces a uniform circulation before discharge. Although this use of water is original with the writer in the method of its application, its first employment to control the temperature of the bearing surfaces of oil-testing machines is due to Monsieur G. Adolphus Hirn, and is described

DIAGRAM 1.—COEFFICIENT OF FRICTION AT DIFFERENT PRESSURES.
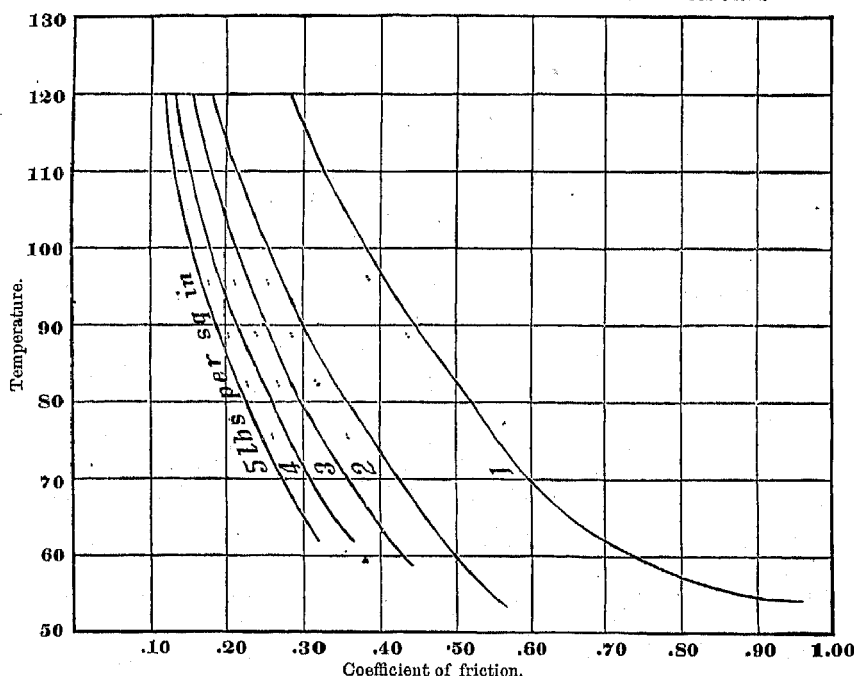
by him in a paper on the subject of friction, read before the Société Industrielle de Mulhouse, June 28, 1854. M. Hirn, however, confined his attention chiefly to the determination of the mechanical equivalent of heat, as measured by the amount of heat imparted to the circulating water, expressed in the work of friction. His investigations of lubrication with this apparatus were confined to the friction of lard and olive oils at the light pressure of about $1\frac{4}{10}$ pounds to the square inch. Mr. Charles N. Waite, of Manchester, New Hampshire, has independently, and I believe originally, made use of water in a friction machine, and has performed good work in the limit of his experiments.

A protection of wool batting and flannel, to guard the discs against loss of heat by radiation, diminishes the escape of heat to about two degrees per hour, which loss is not appreciable when observations are taken within a few seconds' interval. A thin copper tube, closed at the lower end, reaching through the cover, extends to the bottom of the disc; the bulb of a thermometer is inserted in this tube, and measures the temperature of the discs; an oil tube runs to the center of the disc, and a glass tube at the upper end indicates the supply and its rate of consumption, and also serves to maintain a uniform head of oil fed to the bearing surfaces. The rubbing surfaces of both discs were made to coincide with the standard surface plates in the physical laboratory of the Institute of Technology (Boston, Massachusetts), and their contact with each other is considered perfect.

a The tables which accompany this paper are not introduced here. They may be found in the proceedings of the American Association for the Advancement of Science for 1880, pages 197-221.

After this surface was finished the bronze disc was treated with bichloride of platinum, which deposited a thin film of platinum upon the surface. Upon the application of the discs to each other the steel disc rubbed off the platinum from all parts of the surface, showing the perfection of contact. This nicety of construction enables a film of oil of uniform thickness to exist between the surfaces, and the resistances are not vitiated by the collision of projecting portions of the disc with each other. The rounded end of the upper shaft fits into a corresponding depression in the top of the upper disc. This method of connection retains the disc over the proper center, yet it is allowed to sway enough to correct any irregularity of motion caused by imperfection of construction or wear of the lower disc. To obtain the desired condition of pressure, weights are placed directly upon the upper spindle. The axes of the upper and lower spindles do not lie in the same straight line, but are parallel, being about one-eighth of an inch out of line with each other. Such construction, giving a discoid motion, prevents the disc from wearing in rings and assists in the uniform distribution of the oil. An arm is keyed through the lower part of the upper spindle and engages with projections upon the upper disc. Upon this arm, which is turned to the arc of a circle, whose development is two and one-half feet, a thin brass wire is wrapped and reaches to the dynamometer, so that the tension of the dynamometer is tangential and the leverage is constant for all positions of the upper disc within its range of motion. The dynamometer consists of a simple bar of spring steel fastened at one end and bent by the pull applied at the other. Its deflection is indicated by a pointer upon a circular dial, the motion of the spring being multiplied about eighty times by a segment and pinion. The whole is inclosed in a steam-gauge case.

When completed, the machine was subjected to a long series of tests with the same oil, to determine the accuracy of the results and the best method of procuring them. The operation of the machine under equal conditions with the same oil gives results which are as closely consistent with each other as could be expected from such physical measurements. As an example, four tests of the Downer Oil Company Light Spindle at 100° F., and on different days, gave 0.1145, 0.1094, 0.1118, 0.1094 : mean, 0.1113. * * * Much of the irregularity, slight as it is, is due to the variable speed of the engine. Concurrent results were obtained under equal circumstances, but the coefficient of friction varied, not merely with the lubricants used, but also with the temperature, pressure, and velocity. The results of my own experiments on mediate friction do not agree with the laws of friction as given in works on mechanics, but the coefficient of friction varies in an inverse ratio with the pressure, as shown graphically in the diagram (page 204).

These curves belong to the hyperbolic class of a high degree; but I have not been able to deduce an equation which will answer to the conditions of more than one, because the law of the curves is modified by a constant, dependent upon the individual sample of oil used. A little difference in the sample would cause a difference in the line of curve. Reference is made to diagram 2, showing the coefficient of friction under equal ranges of temperature and velocity, but with a different series of pressures.

DIAGRAM 2.—CURVES SHOWING CHANGES OF COEFFICIENT OF FRICTION UNDER VARYING CONDITIONS.
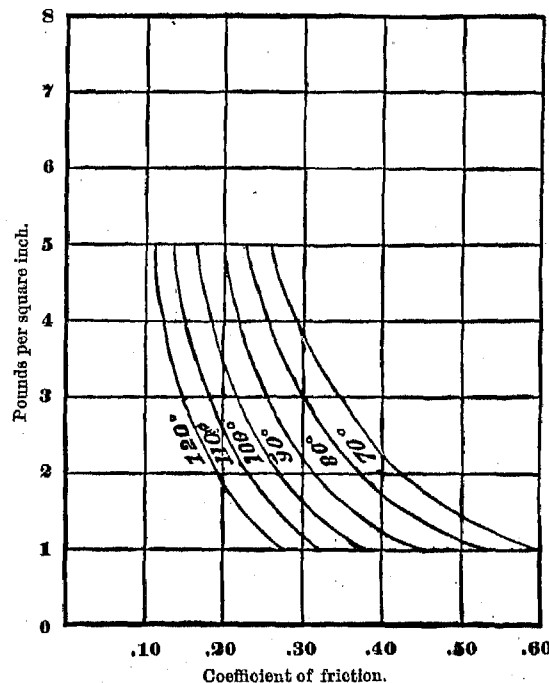
Coefficient of friction at 100° and 500 revolutions per minute :

Pressure per square inch.	Coefficient of friction.
1 pound	0. 3818
2 pounds	0. 2686
3 pounds	0. 2171
4 pounds	0. 1849
5 pounds	0. 1743

The ratio of the changing coefficient varies with the temperature at which the range of results is taken.

Friction varies with the area, because the adhesiveness of the lubricant is proportional to the area, and the resistance due to this cause is a larger fraction of the total mechanical effect with light than it is with heavy pressures.

The limit of pressure permitting free lubrication varies with the conditions; for constant pressures and slow motion it is believed to be about 500 pounds per square inch, while for intermittent pressures, like the wrist-pin of a locomotive, the pressure amounts to 3,000 pounds per square inch. It has been stated that about 4,000-foot pounds of frictional resistance per square inch is the maximum limit of safe friction under ordinary circumstances.

As the results of this preliminary work indicated that the coefficient of friction varied with all the circumstances, it was necessary to simulate the conditions of specific practical applications to determine the value of a lubricant for such purposes.

It was decided to begin these investigations with spindle oils, and therefore the machine was loaded with 5 pounds to the square inch and run at about 500 revolutions per minute, as the oil is then submitted to conditions of attrition corresponding to those met with in extremes of velocity and pressure, in the case of a Sawyer spindle running at 7,600 revolutions per minute, with a band tension of 4 pounds, and the results subsequently given refer only to the friction under these conditions, except when definitely stated to the contrary.

This particular spindle was selected because, of the 5,000,000 ring spindles in the United States, about 1,500,000 are of this manufacture, and in a large number of the remainder the conditions of lubrication are quite similar.

In a Sawyer spindle the step measures $\frac{5}{8}$ by $\frac{1}{10}$ inch, and receives $\frac{7}{8}$ of the pull due to the band. If that tension is 4 pounds, $3\frac{1}{2}$ pounds are transmitted to the step, whose projected area is $\frac{9}{16}$ square inch. The pressure per square inch is, therefore, $5\frac{1}{2}$ (say 5) pounds.

The diameter of the spindle at bolster is 0.28″, or 0.8976″ in circumference. At 7,600 revolutions per minute its velocity amounts to 6,685″, or 557 feet, per minute; and the mean area of the discs of the oil machine must revolve at this speed.

To illustrate, let—

$$R = \text{outer radius of disc} = 2.656 \text{ inches.}$$
$$r = \text{inner radius of disc} = 1.435 \text{ inches.}$$
$$n = \text{radius of circle bisecting the area.}$$

Fractional area of annular disc =	$\pi(R^2 - r^2)$	(1)
area of outer half =	$\pi(R^2 - n^2)$	(2)
$2\pi(R^2 - n^2) =$	$\pi(R^2 - r^2)$	(3)
$2\pi R^2 - 2\pi n^2 =$	$\pi R^2 - \pi r^2$	(4)
$2R^2 - 2n^2 =$	$R^2 - r^2$	(5)
$-2n^2 = -$	$R^2 - r^2$	(6)
$2n^2 =$	$R^2 + r^2$	(7)
$n^2 =$	$\dfrac{R^2 + r^2}{2}$	(8)
$n =$	$\sqrt{\dfrac{R^2 + r^2}{2}}$	(9)

$$\text{Length of line bisecting the area} = 2\,\pi\,n = \sqrt{\frac{4\pi^2(R^2+r^2)}{2}} \qquad (10)$$
$$= \sqrt{2\pi^2(R^2+r^2)} \qquad (11)$$
$$= \sqrt{2 \times 9.87(7.05+2.11)} \qquad (12)$$
$$= \sqrt{19.74 \times 9.16} \qquad (13)$$
$$= \sqrt{180.8184} \qquad (14)$$
$$= 13.45 \text{ inches.}$$
$$= 1.12 \text{ feet.}$$

To give a desired fractional velocity of 6.685 inches per minute the discs must revolve at 6,685 divided by 13.45 = 497 (say) 500 revolutions per minute. To recapitulate: By revolving the disc at 500 revolutions per minute, with a pressure of 5 pounds per square inch, the oil is submitted to conditions of attrition corresponding to those in the extremes of velocity and pressure met with in a Sawyer spindle revolving at 7,600 revolutions with a band tension of 4 pounds.

My reason for giving such a detailed statement is, because the value of investigations upon this subject must be measured by the precision with which all the conditions are observed.

The apparatus is used in the following manner to measure the coefficient of friction of oil: After cleaning with gasoline and wiping carefully with wash leather, the discs are oiled and run for about five hours, being kept cool by a stream of water circulating through the upper disc. From time to time they are taken apart, cleaned, and oiled again. After using any oil, even if the discs are afterward cleaned, the results with the oil subsequently used give the characteristics of the previous oil, and it is only after thirty-five to forty-five miles of attrition that these results become consistent with each other, each succeeding result, meantime, approaching the final series. This seems to indicate that friction exists at the surface of the two discs, between the film of oil acting as a washer and the globules of oil partially embedded within the pores of the metal. If the dense bronze and steel retain the oil despite attempts to remove it, how much longer must it require to replace the oil in machinery with a new variety whose merits are to be tested? These experiments confirm the wisdom of the increasing use of cast-iron for journals, as its porosity enables it to contain and distribute the lubricant.

When the discs are ready to test the oil the apparatus is cooled by the circulation of water, the flow of which is stopped when the machine is started. At every degree of temperature the corresponding resistance is read on the dynamometer. When the thermometer indicates a temperature of sixty degrees, the counter is thrown in gear and the time noted. When one hundred and thirty degrees is reached, the counter is thrown out of gear and the time noted. This not only gives the velocity of the rubbing surfaces, but the number of revolutions required to raise the temperature a stated number of degrees, and is a close criterion of the oil. The coefficient of friction is the ratio of the pressure to the resistance, and is deduced in the following manner:

$$P = \text{Weight on discs.}$$
$$R = \text{Outer radius of frictional contact.}$$
$$r = \text{Inner radius of frictional contract.}$$
$$N = \text{Number of revolutions per minute.}$$
$$W = \text{Reading on dynamometer.}$$
$$\varphi = \text{Coefficient of friction.}$$

In the friction of annular discs the portions of the surface near the perimeter have a greater leverage than those near the center. The mean sum of these moments is found by the calculus.

Let e be the radius of any infinitesimal narrow ring or band. Then will—

Width of band $= de$ . . . . (1)
Length of band $= 2\pi e$ . . . . (2)
Area of band $= 2\pi e\, de$ . . . . (3)
Moment of band $= 2\pi e^2 de$ . . . . (4)
The expression for the area of an annular disc is $\pi(R^2 - r^2)$ . . . . (5)

To express the moment of a ring in terms of an annular surface, divide Eq. 4 by Eq. 5, as follows:

$$\frac{2\pi e^2 de}{\pi(R^2 - r^2)} = \frac{2e^2 de}{R^2 - r^2} = \frac{2}{R^2 - r^2}\, e^2 de = \text{Moment in terms of disc} \quad (6)$$

$$\text{Moment of whole disc} = \frac{2}{R^2 - r^2}\int e^2 de \quad (7)$$

$$\text{Integration of whole disc} \quad \frac{2}{R^2 - r^2}\left\{\frac{e^3}{3}\right\}_r^R \quad (8)$$

$$\text{Substituting the limits } R^2 - r^2, \frac{R^3 - r^3}{3} \quad (9)$$

and calling the work of friction $= \varphi P$ . . . . (10)

$$\text{Statical moment of friction of disc} = \frac{2\varphi P(R^3 - r^3)}{3(R^2 - r^2)} \quad (11)$$

$$\text{Mechanical effect} = \frac{4\pi\varphi P(R^3 - r^3)}{3(R^2 - r^2)} \quad (12)$$

$$\text{Foot pounds at any velocity} = \frac{4\pi\varphi P(R^3 - r^3)N}{3(R^2 - r^2)} \quad (13)$$

As previously stated, the dynamometer exerts a pull at the end of a lever whose development is $2\frac{1}{4}$ feet.

$$\text{Resistance of dynamometer} = \frac{5W}{2} \quad (14)$$

$$\text{Resistance of dynamometer in foot pounds at any velocity} = \frac{5WN}{2} \quad (15)$$

Then as the total friction = the resistance of the dynamometer,

Eq. 13 = Eq. 15

i. e., $\dfrac{4\pi\varphi PN(R^3 - r^3)}{3\ (R^2 - r^2)} = \dfrac{5WN}{2}$

Simplifying we have

$$8\pi\varphi PN(R^3 - r^3) = 15WN(R^2 - r^2) \quad (16)$$
$$8\pi\varphi P\ (R^3 - r^3) = 15W\ (R^2 - r^2) \quad (17)$$

$$\varphi = \frac{15W(R^2 - r^2)}{8\pi P(R^3 - r^3)} \quad (18)$$

$$\text{Separating the constants, } \varphi = \frac{15(R^2 - r^2)W}{8\pi(R^3 - r^3)P} \quad (19)$$

and $R = 0.2214$ feet
        $r = 0.1211$ "
        $R^3 = 0.01083$ $R^2 = 0.0489$
        $r^3 = 0.00177$ $r^2 = 0.0146$
        $R^3 - r^3 = 0.00906$, log. 7.9571282 $R^2 - r^2 = 0.0343$, log. 8.5352491
        $\pi = 3.1416$, log. 0.4971499 $(R^2 - r^2)$ log. 8.5352491
        8   "   0.9030900   15 log. 1.1760913
                ‾‾‾‾‾‾‾‾‾‾   ‾‾‾‾‾‾‾‾‾‾
                9.3573681   9.7113404
                9.7113404
                ‾‾‾‾‾‾‾‾‾‾
                0.3539723 = 2.259
                        $2.259W$
        $$\varphi = \frac{2.259W}{P} \quad (20)$$

This equation was solved for each reading of the dynamometer with five pounds pressure on the square inch, and the results tabulated in a convenient form for computing the coefficient of friction from the observed results.

The table on page 208 shows the resistance of friction at 100°, 500 revolutions, for various pressures.
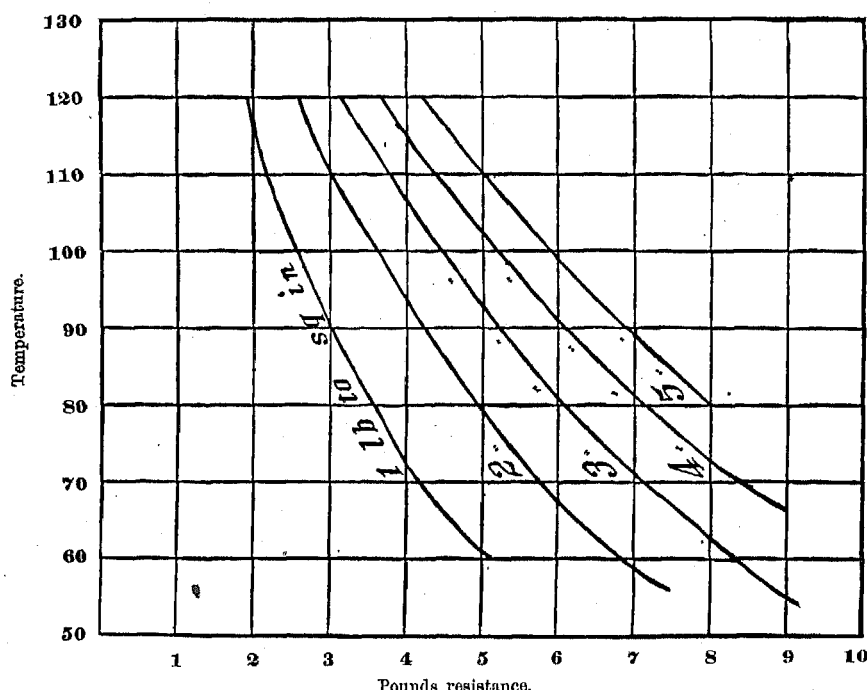
RESISTANCE OF FRICTION AT 100°.

Pressure, pounds.	Resistance on dynamometer. Pounds.	Equivalent band tension.
1	2.62	0.8
2	3.68	1.6
3	4.48	2.4
4	5.28	3.2
5	5.98	4.0

For further detailed results, reference is made to diagram 3.

DIAGRAM 3.—RESISTANCE OF FRICTION AT DIFFERENT PRESSURES.

Pounds resistance.

These results seem to be intimately relevant to the most desirable limit of tension to the spindle-band methods of operating cotton-spinning machinery. By weighing the band tension in various mills it was found that the practice of tying bands lacked uniformity. As an example of this variation: in one mill the bands of a single coarse frame are reported to vary from 1 to 16 pounds. In another mill, on finer work, a number of spindles had a range of from ¼ to 2½ pounds, and in a third mill the band tension was between the limits of ¼ to 5 pounds. The effect of atmospheric changes upon the fiber of textile bands renders it impossible, with the present method of constructing frames, to keep them at a uniform tension, but this variation can be reduced by a little care. Is it not worth while for each spinner to learn the proper band tension required for his special work, and then keep within those limits? The whole power required to run the frame would not vary in direct proportion to the varying resistance due to the friction of spindles at various pressures, because the resistance of the friction in other parts of the frame connected with the spindles, the actual spinning of cotton fibers, and the alternate contraction and expansion of the bands, are conditions which are more nearly constant, and in no case do they vary in proportion with the friction of the spindle, yet the variation is large, as shown by the following experiment made with the frame:

Mr. George Draper, in a communication to the *Industrial Record* of June 1, 1879, gives the following valuable data on this subject: A frame of Sawyer spindles was taken spinning No. 30 yarn, ordinary twist, the front rolls running 95 revolutions per minute. The rings were of 1⅜ inches diameter, and the traverse of the yarn on the bobbins 5¼ inches. The dynamometer was applied, and the power required to drive the spindles, with a side pull of the bands averaging 2 pounds to a spindle, was ascertained. The bands were then cut and a new set put on with a side pull of 3 pounds per spindle, and the frame tested again, all things remaining as before. The operation was then repeated at 4, 5, 6, 7, 8, and 9 pounds side pull per spindle, with the result shown in the following table.

Calling the amount of power required to drive the spinning frame with—

2 pounds tension on the bands .... = 100
3 pounds tension on the bands .... = 117
4 pounds tension on the bands .... = 131
5 pounds tension on the bands .... = 144
6 pounds tension on the bands .... = 159
7 pounds tension on the bands .... = 177
8 pounds tension on the bands .... = 197
9 pounds tension, considerably more than double.

The lubricant used is one of the most important factors in the cost of power. In the present condition of engineering science it is impossible to state what exact proportion of the power used by a mill is lost in sliding friction, but in a print-cloth mill only about 25 per cent. of the power is utilized in the actual processes of carding, spinning, and weaving the fiber, not including the machinery engaged in the operation, leaving 75 per cent. of the power as absorbed by the rigidity of belts, the resistance of the air, and friction. The coefficient of friction, under the conditions submitted by my oil-tester, varies, at 100°, 500 revolutions from 7.56 per

cent. in the case of 32° Ex. machinery oil manufactured by the Downer Oil Company, to 24.27 per cent. in the case of neats'-foot oil; and the result of this investigation confirms me in the opinion that the successful operation of a spinning frame is far more closely dependent upon the individual management in respect to the conditions of band tension, lubrication, and temperature of the spinning-room than all other causes combined. Not that some forms of spindle are not superior to others, but that, without wise supervision, the most desirable forms of spindle must fail to show the merits due to the skill of their promoters. It may be stated that, within a close approximation, the lubricating qualities of an oil are inversely proportional to its viscosity; that is, the friction decreases with the cohesion of the globules of the oil for each other. The endurance of a lubricant is in some degree proportional to its adhesion to the surfaces forming the journal. An ideal lubricant in these respects would be a fluid whose molecules had a minimum cohesion for each other and a maximum adhesion for metallic surfaces. The viscous oils will also adhere more strongly to metals, and hence, under the conditions of heavy bearings, it is obligatory to use such thick lubricants, knowing that the employment of an oil with great frictional resistance is infinitely preferable to the attempt to use an oil so limpid that it could not be retained between the bearings. With light pressures the more fluid oils are admissible, and in all cases the oils should be as limpid as the circumstances will permit. Oils with great endurance are apt to give great frictional resistance, and in the endeavor to save *gallons* of oil many a manager has wasted *tons* of coal. The true solution of solving the problem of lubricating the machinery of an establishment is to ascertain the consumption of oil and the expenditure of power, both being measured by the same unit, viz, dollars.

The fluidity of the oils was measured by the following apparatus: A pipette was placed within a glass water-jacket, where the temperature was controlled and kept constant by circulation from a reservoir kept at the desired temperature. The capacity of the bulb is twenty-eight cubic centimeters and the orifice measures three and a half inches long and 0.039 of an inch in diameter.

The oil was drawn into the bulb of the pipette, and after the whole was brought to the desired temperature the time required for its discharge was accurately noted by a stop watch.

These observations were made on each of the oils for a series of temperatures varying from 50° to 150° F.

If the fluidity of an oil is the measure of its lubricating qualities, these observations would not be identical with the frictional results, because the pressure in this case was that due to a head of about five inches of oil, or about one-sixth of a pound to the square inch and rubbing against a glass surface; while with the frictional machine the pressure was five pounds to the square inch, and the surfaces bronze and steel.

In both cases, however, the character of the surfaces and the pressures were uniform conditions, and therefore they would not affect the relations of either set of experiments in their consistency with each other. If the lubrication and fluidity of oils followed the same law of variation with the temperature, the results of one would be directly proportional to those in the other, provided that all other conditions were preserved constant. Such comparisons showed that the relations of the fluidity to the lubricating qualities did not follow any uniform ratio.

At a low rate of temperatures the fluidity increased faster than the lubricating quality of the oil; between about 70° and 110° the coincidence was quite close; at higher temperatures the fluidity does not increase so fast as the lubrication. There was not a very close correspondence between the fluidity of oils at the same coefficient of friction.

The result of these investigations upon the relation of fluidity to lubrication seems to indicate that fluidity is a concomitant rather than a cause of the anti-frictional qualities of a lubricant.

In the case of mining drills operated by condensed air, an intense cold is produced at the liberation of air, and on some such bearings kerosene oil is the only lubricant which can be used. I think it extremely probable that at these low temperatures the viscosity of kerosene oil is equal to that of lubricating oils at the average temperature of bearings in general use. On the other hand, only the most viscous oils can be used in such extremely high temperatures as the cylinder and steam-chest of steam-engines.

According to the results which I have obtained, the coefficient of friction at 50° is about 75 per cent. in excess of that at 75°, and it seems to me that the manager of every mill which is run by steam ought to consider the question of the temperature of the mill in early morning during the winter months, whether, as a matter of economy, it is cheaper to warm a mill by increased friction on Monday morning, or to keep the mill and machinery warm during the interval from the preceding week.

The humidity of the atmosphere is an important factor in the mechanical operation of textile machinery, as well as in the fabrication of cotton. A year ago I submitted to the New England Cotton Manufacturers' Association measurements showing the effects of humidity on textile bands, and I am also of the opinion that there is a difference of friction in machinery due to atmospheric influences upon the lubricant.

Possibly the moisture condensed upon the cold metal from the atmosphere becomes commingled with the oil and thereby reduces its viscosity, diminishing the friction.

The question of endurance of oils has not been given in these experiments, because the consumption of oil varies with the temperature, and it is proposed to investigate the matter subsequently by running the machine and controlling the temperature of the discs to 100° by the circulation of water. The amount of oil consumed could be very easily measured by the difference in the level of the glass feeding-tube or the weight of the oil required to preserve it at that level during the experiment.

In the detailed results the friction is given for the whole range of temperatures, but in the following summary 100° has been selected as the temperature which most nearly corresponds to the heat of spindle bearings.

To ascertain these temperatures, holes were drilled in the rails of a spinning frame, passing as near the bolsters and steps as possible; the bulbs of thermometers were inserted in these holes, and while the frame was in operation 2,586 readings were taken, covering a period of four weeks. The temperature of the air was noted from a thermometer placed in the middle of the frame.

The mean temperature of the bolsters was 8.10° F., and of the steps 6.74° F., above the temperature of the room.

Other experiments were made to learn the temperature of the bearings of the shafting. Holes about half an inch in diameter were bored in the upper cap of such journals, and a thin copper tube, closed at the lower end, inserted and extended nearly to the shaft. This tube contained water, and the temperature was measured by a thermometer placed therein. The temperature of the room was measured by a thermometer hung near the bearing. There were journals in good running order whose temperature at the frictional surfaces was 140° F. This method of using thermometers was first suggested by Mr. Edward Atkinson, and I consider it the most accurate test of the anti-frictional qualities of a lubricant at the service of those in charge of machinery.

Great pains have been taken to procure pure samples of the oils experimented with, and they were obtained directly from the manufacturers; and to the courtesy of Mr. Thomas Bennett, jr., I am indebted for a large number of samples of sperm oils which were procured by him directly from the whale-ships or refiners.

PRODUCTION OF PETROLEUM.

The following table gives the coefficient of friction at 100° F. and 500 revolutions, with a pressure of 5 pounds to the square inch:

No. of sample.	Kind of oil.	Coefficient of friction at 100°.	No. of sample.	Kind of oil.	Coefficient of friction at 100°.
1	Mineral oil	0. 1635	100	Mineral oil	0. 1309
28	Mineral oil	0. 1732	3	Lard	0. 2181
10	Mineral oil	0. 1187	4	Bleached winter sperm A	0. 1067
14	Mineral oil	0. 1233	5	Bleached winter sperm B	0. 1217
19	Mineral oil	0. 1208	6	Bleached winter sperm C	0. 1170
7	Mineral oil	0. 1113	9	Bleached winter sperm D	0. 0956
20	Mineral oil	0. 1132	18	Bleached winter sperm E	0. 1141
8	Mineral oil	0. 0756	17	Unbleached winter sperm	0. 1147
2	Mineral oil	0. 1476	21	Seal oil	0. 1608
11	Mineral oil	0. 1493	22	Neat's-foot	0. 2427
12	Mineral oil	0. 1201	23	Mixed animal and mineral oil	0. 1608
15	Mineral oil	0. 2243	24	Mixed animal and mineral oil	0. 1377
95	Mineral oil	0. 0973	25	Mixed animal and mineral oil	0. 1190
96	Mineral oil	0. 0050	90	Paraffine	0. 1247
13	Mineral oil	0. 1190	92	Paraffine mixed with one-fifth sperm	0. 1185
16	Mineral oil	0. 1103	93	Paraffine mixed with one-third neat's-foot	0. 1347
91	Mineral oil	0. 1360	94	Unknown sperm	0. 1307
98	Mineral oil	0. 1180			

Chemical examinations of these oils by Mrs. Ellen H. Richards, of the Women's Laboratory, Institute of Technology:

No. of sample.	Flash of vapor.	Loss of evaporation in 12 hours at 140° F.	Nitro-sulphuric acid test.
	Degrees.	Per cent.	
10	338	1. 3	Dark yellow, with much cake.
7	314	2. 7	Dark yellow, some cake.
8	284	5. 5	Slightly yellow, only a few flakes of cake.
2	316	3. 7	Dark yellow, thin layer of cake.
11	324	3. 9	Slightly yellow, not on brown specks.
12	318	3. 3	Yellow, not a single flake, no solid matter.
15	286	7. 2	Turned dark, gives a black layer of gum.
13	322	1. 9	Quite an amount of cake.
16	282	5. 0	Do.
3	....	+0. 4	Hardened with much acid to a white solid mass.
9	....	+0. 3	Thickened up a little, like jelly.

With castor oil the friction was so great as to throw off the belt driving the machine; and as the time alloted for this work expired on that day, other arrangements for a wider belt could not be made, and it can only be said that its friction exceeds that of any other oil given in these tables. * * *

The anti-frictional properties of these oils under the conditions of these experiments are expressed in the following order:

No. of sample.	Kind of oil.	Coefficient of friction at 100°.
8	Mineral	0. 0756
9	Bleached winter sperm	0. 0956
16	Mineral	0. 1103
7	Mineral	0. 1113
18	Bleached sperm	0. 1141
17	Unbleached sperm	0. 1147
13	Mineral	0. 1190
12	Mineral	0. 1201
19	Mineral	0. 1208
2	Mineral	0. 1476
21	Seal	0. 1608
28	Mineral	0. 1732
3	Lard	0. 2181
15	Mineral	0. 2243
22	Neat's-foot	0. 2427

It is no disparagement to the qualities of an oil that it is low in the foregoing list, except so far as it relates to the resistance of friction under these conditions. For circumstances of great pressure and slow motion, I am of the opinion that the order of the list would be varied; and if the question of endurance were only to be considered, still another change in the order would be necessary.

A portion of a lot of unbleached sperm oil (sample 17) was bleached expressly for these tests (sample 18), but the results of the two are so nearly uniform as to be practically identical. The result of bleaching does not affect the anti-frictional properties of the oil, although it undoubtedly reduces its gumming qualities. The friction of sperm oil is subject to sudden variations, which occur at

certain temperatures for the same sample of oil. The explanation of this lies in the fact that sperm oil consists of a large number of varieties of spermaceti, each of which is liquefied at certain temperatures, at which the oil is relieved of waxy, or at least gelatinous particles, and becomes a more perfect lubricant. *   *   *   *

The friction of lard oil for high temperatures exceeds that of any other lubricant in the list; and this adhesive quality enables it to remain on tools used for cutting iron.

In conclusion, it may be stated that the data necessary to determine the safety and efficiency of a lubricant comprise:

1. The flashing point of its vapor, which is ascertained by slowly heating a sample over an oil bath, quickly passing a small flame over the oil and noting the temperature at which the vapor first flashes. The danger from an oil does not arise from the point at which the oil actually ignites, but at the lower temperature, when the inflammable vapor bursts into flames, which communicate fire to a distance limited only by the extent of the vapor.

2. The quantity of such volatile matter is important both as respects safety and value. The heat of friction liberates that portion of the oil which is volatile at the temperature of the bearings, filling the mill with a dangerous noxious vapor, and also dissipates in the air a portion of the oil which is paid for by the gallon, but does not serve to give any return of value in lubrication. The quantity of matter volatile under 140° F. is measured by heating a known weight of oil in a watch-glass and maintaining a constant temperature of 140° F. for 12 hours. This simulates the conditions of the temperature of the bearings mentioned previously and the maximum time that it would be consecutively heated. In the case of mineral oils the loss from evaporation varied from less than 1 up to 30 per cent. With animal and vegetable oils there is a slight gain in weight, due to oxidation.

3. The tendency to spontaneous combustion is estimated by a uniform amount of cotton-waste smeared with a certain quantity of oil. A thermometer whose bulb extends to the center of the mass indicates any rise of temperature due to oxidation. Any gain of weight during the preceding evaporation test shows a liability to spontaneous ignition.

4. Freedom from acid is an important factor in oil, because acid is a cause of corrosion of metals, and will tend to remove the oil from the frictional surfaces when adhesion is indispensable. The presence of acids is shown by corrosion of copper.

5. The anti-frictional properties of an oil can be measured only by direct trial under the desired conditions of pressure, velocity, and temperature. The results of these experiments show that a lubricant must have a certain adhesion to the frictional surfaces to maintain free lubrication, but beyond that point the adhesiveness of the oil resists the motion of the surfaces, increasing the friction. A thick oil gives greater frictional resistance than a thin one; and when ease in running is the object the most limpid oil should be used consistent with the specific circumstances of the bearing. In general terms, the specific gravity of an oil gives no indications of its value as a lubricant in qualities of viscosity, body, or endurance. *   *   *

When this paper was read at the meeting of the American Society of Mechanical Engineers, Professor R. H. Thurston spoke as follows:

Mr. Woodbury in his paper made some reference to the fact that the coefficients of friction, as ordinarily stated, are not found to be strictly correct; in other words, that there are no such losses in ordinary practice. Then he has shown you here how seriously the temperature of the lubricant affects the coefficient of friction. You will notice that the work done is all at extremely light pressures. It is simply due to the pull of the band, and the resultant of that and the resistance of the work of the spindle. It is exceedingly light, and it is for that reason that we get what appeared to be extremely high coefficients of friction. In the table exhibited you will see that the coefficients run from 7¼ up to about 20 per cent., the highest figure being lard oil and a special grade of machinery oil, which are each about 22 per cent. Now, a fact which was not brought out so strongly by the paper as it might have been is, that this coefficient is also affected very largely by the pressure per square inch put upon the journal, and what I intended specially to remark upon was the fact that these coefficients do not represent the values of the coefficients obtained in ordinary engine work, but are the coefficients obtained in extremely light work, as in the spinning-frames of cotton-mills. If we use the same lubricating material, and the same surface pressure, rising above that to fifty pounds, we will find the coefficients come down in value to a fraction of the figures given on the scale. Carrying the pressure up to a very common figure, such as we might get with any machine work, of 100 or 200 pounds, we will find that the coefficient is reduced. I have had occasion to make tests of various kinds of oil between various sorts of surfaces, and, under varying pressures and temperatures, up to pressures of 1,500 pounds to the square inch, and for a very short period of time 2,000 pounds to the square inch, and at temperatures which ran from the ordinary atmospheric temperature to above the boiling point of water, and I find that upon the crank-pins of steam-engines, such as are sometimes used on the North River boats, carrying the pressure of a thousand pounds to the square inch, instead of a coefficient of friction of 5 per cent. we get one-tenth of 5 per cent.—one-half of 1 per cent. for the coefficient of friction—so that the field explored by Mr. Woodbury is limited to these extremely low temperatures. They do not represent the results as ordinarily obtained, or exceptional results obtained by putting on tremendously high pressures, so that if we take the very best of lubricating materials—sperm oil is the best I have ever found for heavy pressures—and put a pressure upon it of a thousand pounds to the square inch, then, instead of the text-book coefficients of friction, all the way from 4 to 7 per cent., we get figures that run to one-tenth of that amount. I have obtained coefficients of friction with sperm oil as low as one-fourth of 1 per cent.

The pressure, therefore, at which you are working is one of the very important elements in determining what is to be the coefficient of friction to be assumed in design.

Now, I spoke of this partly as a commentary on this paper and partly as a commentary on that of Mr. Hoadley. Mr. Hoadley shows us that we may divide the circumference described by the crank-pin by horizontal and vertical lines, and he calls the upper and lower of the two sections of his circumference the work-doing parts of the traverse of the crank-pin, and the end sections he calls the work-using sections.

Now he shows us what is the effect of friction in reducing the efficiency of engines where we put full pressure on the crank-pin at either end of the stroke; but it must be observed, as a commentary upon that statement, that these figures are very much smaller than we have been accustomed to assume. The friction of the crank-pin in a well-made engine, with a good bronze box, running on good steel journals, ought to come down to a fraction of 1 per cent. That being the case, we get the result that Mr. Porter indicated, that the loss of power at the two ends of the stroke becomes insignificant, more insignificant than I presume he had supposed.

A remark was also made by another member of the society upon our determinations of the value of lubricating oils for steam-cylinders. In a long series of experiments, which I have had occasion to make on lubricating oils to be used in steam-cylinders, I have taken oils furnished in the market for that purpose and tested them at the temperature of the steam-cylinder, bringing them up to a temperature of 250° or 300°, and some cases 350°, and I found that the value of the oil for lubricating purposes within the steam-cylinders is by no means the same as its value for lubricating on the crank-pin and other external parts not subjected to high temperatures, and that the oil giving the best results on the crank-pin may give poor results in the cylinder.

In several cases I have found that oils that were among the best for ordinary use were among the poorest for cylinder work, while other oils that were not nearly so good for external use were among the very best for use within the steam-cylinder. So no one can tell what is the value of an oil for the purpose to which he applies it until he subjects it to a test under precisely those conditions.

Mr. Woodbury presented us with the results of work done under the precise conditions of actual use. He runs the spindles at the ordinary speed, and runs them as in ordinary spinning frames, and then measures the friction, and the data he gives are of course absolutely reliable as determining the results to be met with under that set of conditions. That is one reason why we may rely so absolutely, I presume, upon his results. He has determined under these conditions what is the comparative value of a large number of oils; but I wish to renew his caution that we are not to take these results, which represent the relative value of oils for spindles, as representing the relative value of those oils for crank-pins or the lubrication of steam-cylinders. Another remark was made in the paper, apparently incidentally, that a man may save a considerable amount of money in the purchase of his oils, while losing at the same time a vastly greater amount in paying his coal bills, and that leads to the question how are we to determine the money value of these oils? It is evident that the value to the dealer is not at all likely to be just its value to the purchaser. The money value of the oil to the consumer is something less than the money value of the work that it is going to save him in friction, or the money value of the work that it is going to save him in friction added to the money value of the work it is going to save him in repairs and incidental expenses. If you will take the trouble to determine the cost of the power in any mill or machine-shop in the country, and then assume a change in the coefficient of friction from an average of, we will say, 2 or 3 per cent. to an average of 5 per cent., and see what you can afford to pay for oil that will avoid that increase of friction, you will find probably in every case in which you make the calculation that you can better afford to pay the highest prices in the market for the best oils than to take as a gift the oils which give you the highest coefficients of friction.

I took occasion some time ago to work that up in a specified case—that of Mr. Sellers' shop—I don't remember now what the figures were, but the result was such as to show that we could better pay a good many times the value of the best sperm oil in the market to reduce losses by friction than to take the cheapest oils in the market with the increase of those losses.

The difference between the lowest coefficients and the highest coefficients is about 1 to 3.

But when you are calculating the cost of the power required to overcome this friction, you will find that even slight differences are sufficient to justify you in making your estimate of costs in taking the very highest-priced oil, even if it gives you a very little decrease in the coefficient of friction.

In a circular issued near the close of the year 1880 by Mr. Atkinson, he gives a summary of the results obtained in the research conducted by Mr. Woodbury, and remarks:

Another result of this work has been the invention of the machine on which we can now ascertain the anti-frictional properties of any oil with absolute certainty, and by the use of which we have obtained measurements of the coefficient of friction with an accuracy and uniformity that have never been approached before. * * * Our machine having been adjusted in velocity and other conditions to those of a Sawyer spindle operating at 7,600 turns per minute under a band tension of 4 pounds, it appeared that the difference in power required to overcome the resistance of the parts varied as follows:

The resistance or power required to operate the frictional machine at 100° F., when lubricated with Downer Oil Co. 32 extra machinery oil, amounted to 756, and under the same conditions, with the exception of the substitution of neat's-foot oil as a lubricant, the resistance amounted to 2,427, or three and twenty one-hundredths times as much.

In respect to the same oil at different degrees of temperature in the bearing, the resistance at 50° is about 75 per cent. in excess of that at 75° F.

In respect to the best oil and poorest lubricant at 100° F., the difference is 321 per cent.

In respect to a difference of pressure varying from 1 pound to 5 pounds, the difference is 229 per cent.

By means of experiments applied to a small Sawyer spindle-frame, which could not be reduced to such precise accuracy, but which marked the great variations in power according to the greater or less tension of the bands, other results were reached of the same general character, fully confirming the above conclusions.

The general conclusions reached are, therefore, that although, as a matter of course, there must be a marked difference in power needed between a well-planned and constructed and a badly-constructed spinning-frame, yet, when it is a question between two well-constructed frames, * * * the greatest differences in details (of construction) do not make as much difference in the power required as may be made in the adjustment and tension of the bands or in the quality and condition of the oil, and hardly as much as may be made by variations in the temperature and condition of the atmosphere and of the machine, or in the quality and condition of the stock in use. The uniform tension of the band appears to be the factor of the greatest importance, and the structure of the bobbin of the least, provided the spindle is long enough and heavy or stiff enough to keep the bobbin true and to prevent it from springing under the varying conditions of the atmosphere.

In respect to the best quality of oil to be used on spindles—that is to say, the best oil to be used on light bearings at very high velocity—a few simple rules may now be laid down dogmatically, so far as rules are to be made by experiments on a single machine or from laboratory experiments.

1. A mineral oil that flashes at less than 300° F. does not possess the best qualities for lubrication, and is unsafe in proportion to the lesser degree at which it flashes.

2. A mineral oil that evaporates more than 5 per cent. in ten hours at a heat of 140° F. is hazardous in proportion to the increased percentage of volatile matter, and is also more unfit to be used as a lubricant the more rapidly it evaporates, because the remainder will either become thick and viscous, requiring a high heat in the bearing to make it operate at all, or else, if the oil does not contain such a residuum liable to become thick and heavy, it will leave the bearing dry.

3. All the mineral oils—and also sperm, lard, and neat's-foot oils—appear to reach a nearly uniform coefficient of friction at very greatly different degrees of heat in the bearings. Several kinds of the best mineral oils and sperm and lard oils show a uniform coefficient of friction at the following degrees of heat:

TEMPERATURE AT WHICH THE COEFFICIENT OF FRICTION IS THE SAME.

	Deg. F.
32° machinery (an exceedingly fluid oil)	76
Light spindle	105
Heavy spindle	125
Various samples of sperms	96 to 114
Valvoline spindle	127
White valvoline spindle	122
White loom	111
German spindle	112
A spindle	107
Neat's-foot	170
Lard oil	180

4. Lubrication seems to be effective in adverse ratio to viscosity, *i. e.*, the most fluid oil that will stay in its place is the best to use. Lard oil heated to 130° lubricates as well as sperm at 70° or the best mineral oil at 50°. But of course it is a great waste of machinery to work oil of any kind up to an excessive heat, and there must be the least wear in the use of oil that shows the least coefficient of friction at the lowest degree of heat.

5. The quantity of oil used is a matter of much less importance than the quality. The mill that saves gallons of oil at the cost of tons of coal or dollars of repairs plays a losing game. Mr. Waite's experiments on very heavy bearings at Manchester go far to prove that a considerable quantity of thin fine oil keeps the bearings much cooler and requires less power than a smaller quantity of thick viscous oil. Here let it be observed that a superstition that prevails in favor of using castor oil to cool a hot bearing is without any warrant. No vegetable oil is fit to use as a lubricant; and castor oil is the worst of all, because the most viscous. If used, it will surely set the mill on fire, as it did in the only case of which we have a record.

6. The rule of best lubrication is to use an oil that has the greatest adhesiveness to metal surfaces and the least adherence as to its own particles. Fine mineral oils stand first in this respect, sperm second, neat's-foot third, lard fourth.

7. Cast-iron holds oil better than any other metal or any alloy, and is the best metal to use for light bearings, perhaps for heavy.

8. It has been proved by Mr. Waite's experiments that a highly-polished bearing is more liable to friction than a surface finely lined by filing. The lines left by the file serve as reservoirs for the oil, while the high polish leaves no room for the particles between the metal surfaces.

So far as laboratory experiments may serve as a guide in practice, it therefore appears that fine mineral oils may be made to serve all the purposes of a cotton-mill, and such is the practice in some of the mills that show the very best results in point of economy; next, that the best animal oil to mix with a fine mineral oil, in order to give it more body, is sperm oil; this again accords with the practice of many of the mills in which the greatest economy is attained. Lard and neat's-foot oil are used to give body to mineral oil in some of the best mills; but the results of our work seem *not* to warrant this practice, unless there is some peculiarity in the machinery that makes it more difficult to keep a less viscous or tenacious oil on the bearings. All the mixed oils sold under fancy names we believe must, of necessity, consist of certain proportions of the oils heretofore named, as none of the vegetable or fish oils are fit to be used, and there are no other animal oils that can be had in any quantity. It appears that all varieties of mineral oils are or have been used in print-cloth mills, and are all removed in the process of bleaching, as practiced in print-works. All mineral oils stain more or less, and give more or less difficulty to the bleacher when dropped upon thick cloth or cloth of a close texture. On this point we have been able to establish no positive rule; but as very many kinds are and have been used in mills working on such cloths and are removed we are inclined to the belief that this question is not of as great importance as it has been assumed to be.

These exact results have been obtained under conditions of great velocity and low pressure. Professor Thurston's remarks, quoted on a previous page, apply to the conditions of friction under great pressures and slow motion. We have not, however, yet subjected the lubrication of heavy bearings to so exhaustive a research. Dr. C. B. Dudley, chemist to the Pennsylvania Railroad Company, has been devoting much time recently to the investigation of lubricants for railroads. His results have not been made public. This road and other leading railroads of the country are among the heaviest purchasers of natural lubricating oils that will not thicken at a low temperature. Oils of this quality, as well as reduced oils, are very largely used on railroads, as also some of the petroleum mixtures, such as the " pine-tar compound ", the " galena oils ", and the "plumbago oils ".

A report of a committee of the Railway Master Mechanics' Association of the United States, appointed to examine into and report on the subject of lubricants, recommended a good quality of natural earth oils as the best to use for lubricating machinery and journal boxes. It is less expensive and of a better quality than other oils. When treated so as to reach 28° of gravity, it was found to work with perfect success. It had been reported favorably on from Canada in the north to Kentucky in the south. A test of various oils had been made with the oil-tester on the Lake Shore road; sperm, lard, and tallow were used, and none of them were found to possess qualities which render their use advisable. In their experiments the committee used a machine the size of a regular axle-box, and 50 drops were poured in at a temperature of 60°, and the wheel was allowed to revolve at a rate of speed equaling 35 miles per hour until a temperature of 200° was reached. The length of time, number of revolutions, and amount of friction were all noted. Attention was called to the result obtained from tests with paraffine oil which costs from 25 to 30 cents per gallon, and which has been used on railroads in preference to lard oil. Paraffine oil costing 25 cents, with which six experiments had been made, showed that twenty-four minutes were required to reach the maximum temperature, during which time it gave 11,685 revolutions; castor oil, costing $1 25, which required twenty-eight minutes to reach the temperature allowed, gave 12,946 revolutions; manufactured oils—A, B, and C—costing 35 cents, 90 cents and 25 cents, respectively, required nineteen and one-half minutes, giving from 9,285 to 9,653 revolutions; sperm and tallow required only seventeen minutes to reach 200° temperature, with less than 8,000 revolutions. (*a*)

Paraffine oil that does not boil under 370° C. has been considered the best material for lubricating cylinders at high temperatures. Mineral oil, purified by being shaken with chlorinated soda, from which it is decanted and then shaken repeatedly with milk of lime, and again decanted and then distilled with one-third its volume of solution of caustic soda, is used for the lubrication of watches. (*b*)

a Iron Monger, Supplement, Dec. 13, 1879.   *b* Poly. Cbl. 1859, 575.

CHAPTER II.—THE USES OF PETROLEUM AND ITS PRODUCTS FOR ILLUMINATION.

SECTION 1.—INTRODUCTION.

Crude petroleum has been used in Japan and Burmah for purposes of illumination from an immemorial period. In Burmah the Rangoon tar or oil was burned in earthen lamps. In Persia pencils of dried dung were saturated with the oil and burned, the pencil serving as a wick. In Parma and Modena and other towns in the upper valley of the Po the native petroleum, which is quite fluid and of a light color, has been burned for years both in street lamps and in dwellings. In the valley of Oil creek, and in the salt region of the lower Allegheny and Kiskiminetas, the petroleum obtained from springs and from the salt-wells was used in a contrivance resembling a tea-kettle, often with two spouts (see Fig. 19), for lighting saw-mills and derricks. For these purposes the amber oils of the lower Allegheny were considered superior to the dark oil of Oil creek.

Since the manufacture of petroleum by distillation was commenced there have been several separate products used for illuminating purposes. Most of the illuminating oils have been called "kerosene", a name which was originally adopted as a trade-mark by some firm engaged in the manufacture of coal-oils, but which soon afterward became a common designation applied to a certain class of oils used in common lamps. This word, however, has not been uniformly applied to a substance of uniform kind and quality, but has been used to designate a class of substances prepared in a similar manner from a common crude material, but which in certain respects present a very wide variation. The varieties known to the trade are "Water White", "Standard," and "Prime", the distinctions on which the classification is based relating chiefly to color. There are, however, wide differences between the oils as manufactured by different methods that exist independently of color. The oils may contain too large a proportion of the volatile products of the petroleum; they may contain too large a proportion of the heavy products; they may contain too large a proportion of cracked material; and yet in either case they may, by judicious manipulation, be made to appear of good color while otherwise of inferior quality—a fact which in this country has been almost overlooked, but which has lately attracted some attention in Germany, and will doubtless be more carefully regarded in future. "Color" and "test" have hitherto determined the quality of competitive illuminating oils, but a more careful regard for the quality of such oils would lead to the determination of the relative proportion of light and heavy constituents and the condition of the oil with reference to the presence and amount of sulphur compounds. The quality of oils with reference to these two particulars is not determined by either the color or the test, but a disregard of them seriously affects the quality of the oil as an illuminator. (a) A few years since legislation was obtained in Minnesota which excluded low-test oils from the markets of that state. The following season those markets were stocked with oils, which, to use the English phrase, were mixtures of "tops and bottoms". They were up to the legal test, and were satisfactory in color, but they would become solid at —20° F., and were so heavily charged with sulphur compounds that they blackened at a temperature of 200° F. They were of very inferior quality, and were very successfully used in securing the repeal of the legislation of the preceding winter.

In addition to the ordinary illuminating oils which vary in the manner stated above, the naphthas of different grades have been used in lamps of different kinds. The best lamp in all respects for burning naphtha is that known as the sponge lamp. This lamp is made in a variety of forms, and is filled with sponge, which, on being saturated with the fluid, yields it to the wick and prevents either the spilling of the contents of the lamp or an explosion when the fluid is consumed and air becomes mingled with the vapor. Naphtha is also used in lamps of peculiar construction which have been found especially useful for lighting streets. These lamps are so constructed that the heat of the flame vaporizes the naphtha as it passes through a tube from a reservoir to the burner, where the vapor is burned as if it were a gas jet. This form of lantern is very extensively used, especially in the environs of cities.

Another oil is "mineral sperm", which is distilled from the crude paraffine oils in the preparation of lubricating oils. This oil has a very high boiling point, and flashes at a temperature above 275° F. It is chiefly used in lighting mills, steamboats, and railroad cars, where more easily inflammable oils would be objectionable.

SECTION 2.—SAFE OILS.

While the color of oils is to some extent an indication of their quality, the flash or fire test is the principal guarantee upon which the general public relies for both quality and safety; yet, as has been already stated, the burning qualities are not represented by them. The discussion of the subject of *safe* oils was commenced at a very early date. Among the earliest papers connected with this subject is one published in the *Report of the*

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a See *Vohl's Research*, page 181.

Smithsonian Institution for 1862 by the Hon. Zachariah Allen, of Providence, Rhode Island. In this paper Mr. Allen states that the experiments therein described were undertaken at the instance of the Rhode Island Mutual Fire Insurance Company. The experiments were too simple to be deserving of particular notice here, but the discussion of the subject not only exhibits the acuteness with which the author was accustomed to treat technological questions, but also shows how few facts have been added to the sum of human knowledge concerning the products distilled from petroleum during the twenty years that have elapsed since his paper was written. He says:

To ascertain the comparative qualities of the kerosene oil made in different parts of this country samples were procured and tested by the simple process of pouring some of each kind of oil into a cup by itself, and by placing them all afloat together in a basin of water heated by a spirit lamp, and with a thermometer immersed in the water to indicate the temperature while gradually rising from 60° to 212°. During the progress of the increase of temperature blazing matches were passed over the surface of the oil in each cup successively at short intervals of time, until the increased heat caused sufficient gaseous vapors to arise from each to take fire, which they all finally did, at degrees of temperature varying from 80° to 162°, exhibiting faint flames quivering over the surface of the oil, precisely like those hovering over the surface of spirits of wine or alcohol when similarly kindled. The flames are quite as readily extinguished by a blast of the breath, and not the least symptom of any explosive character became manifest when each one took fire. Until the evaporative point of each sample of oil was produced by the increase of heat applied, and until lambent flames were kindled, burning matches were extinguished when plunged into the coal-oil as effectually as if they had been similarly plunged into water. The average heat at which all the samples emitted sufficient vapor to admit of being kindled was about 125° of Fahrenheit's scale. After ascertaining the temperature requisite to kindle the several samples of coal-oil, it next becomes an interesting subject of investigation to ascertain the heat to which coal-oil is ordinarily elevated while burning in lamps. The results of actual experiments showed that in glass lamps the temperature is increased about 6° and in metallic lamps but 10° or 12° above that of the apartment, which, being 67°, produced a heat in the oil of about 71° to 79°, leaving a considerable range of temperature below the average of 125° above stated. Finding by actual observation that only gaseous vapors arising from the heated oil exhibit the phenomenon of flame whilst ascending and combining chemically with the oxygen of the air, it became manifest that no explosive action could be anticipated to take place from any kind of oil or inflammable spirits unless these gaseous vapors were first evolved by a previous increase of temperature, and then brought into contact with the atmospheric air before applying a match thereto. There being no room left for either the gaseous vapor of the oil or for atmospheric air to combine therewith in the chamber of any lamp entirely filled with oil, every attempt to produce explosive action with a full lamp, at all temperatures up to the boiling-point of water, utterly failed when lighted matches were applied to the open orifice of the lamp. The only result produced by increasing the heat of the coal-oil was an increase in the evaporation of the gas, and a higher jet of flame steadily rising, as from the jet of a gas burner. So long as lamps are kept FULL of oil, or even of explosive camphene or "burning fluid", there can be no explosive action whatever. *For this special reason it may be adopted as a safe rule to cause all* lamps containing highly inflammable liquids to be kept as full as practicable by being daily replenished.

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As the dangerous inflammability of coal-oil appeared to be ascribable to the naphtha not separated therefrom, the following experiments were made to ascertain the extent of the inflammable properties of pure naphtha. Finding that the liquid naphtha evolved sufficient vapors at the ordinary temperature of the atmosphere to become instantaneously kindled into flashing flames, the cup containing it was immersed in a freezing mixture of snow and salt to reduce the temperature to the zero of Fahrenheit's scale. At this low temperature the naphtha appeared to blaze with equal violence. Then a quantity of snow was mixed with the liquid naphtha and thoroughly stirred, for still further reducing the temperature. Even at this extreme degree of cold the naphtha continued to flame so furiously that it was necessarily thrown from the cup upon the ice covering the ground where the experiment was made, in the open air, whilst the thermometer indicated an atmospheric temperature of 19° below the freezing point. The naphtha still continuing to burn upon the surface of the ice, a covering of snow was thrown over it to extinguish the flame. Through this covering of white snow the bright flames still continued to shoot up, presenting to view the extraordinary spectacle of burning snow. On repeating similar experiments on the comparative combustibility of spirits of wine or alcohol, camphene, and burning fluid, they did not emit sufficient gaseous vapors at the freezing point, or 32°, to become kindled into flame when burning matches were plunged therein, but with a little increase of temperature they all became kindled. The preceding experiments seem to exhibit impressively the extraordinary inflammability of naphtha, arising from the facility with which it emits gaseous vapors; the utmost caution is requisite to prevent not only unexpected explosions, but also the almost unextinguishable violence of its conflagration, for practically the application of water does not subdue the conflagration of naphtha in quantity, and only the exclusion of atmospheric air appears to quench the fury of its flames. * * * Petroleum contains a considerable percentage of naphtha, and consequently partakes in a degree of its dangerous properties. * * * In making experiments with the tin vessel of the capacity of a common lamp a single drop of naphtha was found to yield sufficient vapor to produce as much explosive action as could be produced by the most inflammable coal-oil for sale in the market when similarly experimented with; and after every experiment failed to exhibit the slightest explosive tendency of the best kerosene oil, a single drop mingled therewith rarely failed to yield sufficient vapor to manifest its presence by a slight explosive puff when kindled by a lighted match. (a)

These experiments, made in 1862, satisfied Mr. Allen, as a representative of very large manufacturing and insurance interests, that "coal-oil" (*i. e.*, mineral illuminating oil), when properly manufactured by responsible parties, was a safe material for use; and they also established these fundamental facts, which have been made the basis of all the action that has since been taken with reference to this question, viz: That the volatile constituents of petroleum are extremely inflammable liquids; that they mingle with the air with great readiness and form mixtures that explode with great violence; that illuminating oil prepared from coal or petroleum, from which these oils, volatile at a low temperature, are carefully excluded, is a safe illuminating material for ordinary use, while the presence of a very small percentage of the naphtha, added to an oil of unquestioned excellence, produces a dangerous mixture, from the use of which explosions and conflagrations are liable to ensue.

The continued agitation of this subject led to legislation by states, cities, and towns, and also to the manufacture of such oils as would satisfy the requirements of the various laws enacted. The result has been the establishment of different tests, that is, different degrees of temperature at which the oils might produce an explosive

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a *Rep. Smithsonian Inst.*, 1862, p. 330. The name is here erroneously given T. Allen.

vapor or burst into flame. The tests were therefore classified as flash tests and fire tests, and both classes include a range of temperatures between 75° and 175° F. Both the classes of tests have had their advocates; and to meet the requirements of law with most profit on the one hand, and to protect the public in the use of these oils on the other, a large number of apparatus and a variety of methods for their use have been devised.

The conclusions reached by Mr. Allen, that an oil properly manufactured is safe, while one containing naphtha is dangerous, suggests the further conclusion that there must be two standards: one of relative and the other of absolute safety. The object of establishing any test is *simply to determine at what temperature a given sample of illuminating oil, in quantity sufficient to fill a lamp of ordinary size, gives off enough vapor, which, when mingled with air, can form an explosive mixture.* It therefore becomes a matter of merely secondary importance at what temperature such an oil will take fire, as all experience has shown that an explosion has been followed by fire in so many instances that the question of the temperature at which an explosive oil will take fire becomes eliminated as worthless; because the temperature at which an oil will take fire is acknowledged by all parties ·at all acquainted with the facts to be no indication whatever of the temperature at which such an oil will flash. It is immediately asked, if such is the case, why is a fire test ever used? It is sufficient to answer, that it is much less difficult to manufacture oils of a uniform *fire* test than of a uniform *flash* test; hence the efforts of some manufacturers have always been used to secure legislation requiring a *fire* test rather than a *flash* test, and legislators have listened to the presentation of practical difficulties rather than to the objections presented by physicists and philanthropists who have urged the claims of the flash test.

As illustrating the inadequacy of the fire test to protect life and property by detecting dangerous oils, of seven hundred and thirty-six samples of oil examined for the New York city health department more than half did not take fire below 110°, while only twenty-three failed to evolve inflammable vapors below 100°.

Returning to the question of absolute safety, we immediately seek to follow Mr. Allen in his inquiries respecting the temperature attained by the oil while burning in lamps under ordinary conditions. The most elaborate research on record is that undertaken by Dr. C. F. Chandler and published in 1871 in his celebrated report on petroleum as an illuminator. (a) The following extract from this report gives the conclusion reached:

THE TEMPERATURE OF OIL IN BURNING LAMPS.

FIRST SERIES.—TEMPERATURE OF THE ROOM, 73° TO 74° F.

No.	Kind of lamp.	Capacity of lamp.	TEMPERATURE OF THE OIL.				
			After one hour.	After two hours.	After four hours.	After seven hours.	Average for seven hours.
		Ounces.	Deg. F.	Deg. F.	Deg. F.	Deg. F.	Deg. F.
1	Brass hand-lamp	8	85	82	85	86	84.5
2	Brass hand-lamp	24	79	83	84	82	82.0
3	Glass stand-lamp	8	77	78	79	80	78.5
4	Glass stand-lamp	11	77	81	84	82	81.0
5	Glass stand-lamp	20	78	79	79	80	79.0
6	Glass stand-lamp	7	82	80	85	84	82.75
7	Glass stand-lamp	10	84	86	84	82	84.0
8	Glass hand-lamp	9	79	78	85	85	81.75
9	Glass hand-lamp	6	81	82	86	86	83.75
10	Glass hand-lamp	7	80	78	....	....	79.0
11	Brass student-lamp	13	82	80	83	84	82.25
12	Glass stand-lamp	10	81	81	79	78	79.75
13	Brass stand-lamp	11	92	89	88	86	88.75
14	Tin lantern	7	89	86	88	87	87.5
15	Glass bracket-lamp	19	82	82	84	83	82.75
16	Glass stand-lamp	29	82	80	80	84	81.5
17	Brass student-lamp	7	80	....	88	....	84.0
18	Brass stand-lamp	14	84	85	87	87	85.75
19	Brass stand-lamp	12	100	100	92	91	95.75
20	Metal stand-lamp	9	82	82	88	87	84.75
21	Brass stand-lamp	12	91	92	88	85	89.0
22	Bronze stand-lamp	16	83	76	79	85	80.75
23	Glass hand-lamp	....	79	80	82	82	80.75

a Am. C., ii, 409, 446; iii, 20, 41; Mon. Sci., 1872, 676, Dingler, ccv, 587; D. Ind. Z., 1872, 376; W. B., 1872, 873.

With the air of the room at from 73° to 74° F. the temperature of the oil in the burning lamps ranged from 76° to 100° F., the highest temperature of 100° having been reached in a metal lamp at the end of one hour. That this was an exceptionally high temperature is shown by the fact that the highest temperature reached in any other lamp was 92° F. The following is a synopsis of the observations:

	In 23 lamps.	In 11 metal lamps.	In 12 glass lamps.
	Deg. F.	Deg. F.	Deg. F.
Highest temperature reached........	100	100	88
Lowest temperature reached	76	76	76
Average temperature.................	83	86	81

SECOND SERIES.—TEMPERATURE OF THE ROOM, 82° TO 84° F.

No.	Kind of lamp.	Capacity of lamp.	TEMPERATURE OF THE OIL.				
			After one hour.	After two hours.	After three hours.	After four hours.	Average for four hours.
		Ounces.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
	Air of room.....................		82	83	84	83	83
1	Brass hand-lamp	8	92	95	96	95	94.50
2	Brass hand-lamp	24	88	94	94	93	92.25
3	Glass stand-lamp......................	8	84	88	86	84	85.50
4	Glass stand-lamp....................	11	84	86	86	84	85.00
5	Glass stand-lamp....................	20	85	86	87	86	86.00
6	Glass stand-lamp	7	86	87	88	88	87.25
7	Glass stand-lamp....................	10	88	87	89	88	88.00
8	Glass hand-lamp	9	87	90	90	90	89.25
9	Glass hand-lamp	6	87	91	89	87	88.50
10	Glass hand-lamp	7	84	86	86	84	85.00
11	Brass student-lamp...................	13	86	88	88	88	87.50
12	Glass stand-lamp	10	85	86	86	85	85.50
13	Brass stand-lamp	11	104	103	101	101	102.25
14	Tin lantern	7	95	96	94	96	95.25
15	Glass bracket-lamp	19	84	85	84	84	84.25
16	Brass stand-lamp....................	20	84	85	84	84	84.25
17	Brass student-lamp..................	7	87	88	86	84	86.25
18	Brass student-lamp	14	91	93	92	91	91.75
19	Brass stand-lamp...................	12	101	100	98	96	98.75
20	Metal stand-lamp	9	89	92	94	93	92.00
21	Brass stand-lamp...................	12	88	98	94	96	94.00
22	Bronze stand-lamp	16	82	88	88	89	86.75
23	Glass hand-lamp	6	84	86	85	84	84.75
24	Brass student-lamp	10	120	120	120	118	119.50
25	Brass student-lamp	12½	112	115	115	110	115.00

With the air of the room at from 82° to 84° F, the temperature of the oil in the burning lamps ranged from 82° to 120° F. The temperature 120° was exceptional, being confined to one lamp.

SYNOPSIS OF THE OBSERVATIONS.

	In 25 lamps.	In 13 metal lamps.	In 12 glass lamps.
	Deg. F.	Deg. F.	Deg. F.
Highest temperature reached........	120	120	91
Lowest temperature reached........	82	82	84
Average temperature................	91½	96½	86

PRODUCTION OF PETROLEUM.

THIRD SERIES.—TEMPERATURE OF ROOM, 90° TO 92° F.

No.	Kind of lamp.	Capacity of lamp.	TEMPERATURE OF THE OIL.				
			After one hour.	After two hours.	After three hours.	After four hours.	Average for four hours.
	Air of room............................	Ounces.	Deg. F. 92	Deg. F. 90	Deg. F. 92	Deg. F. 90	Deg. F. 91
1	Brass hand-lamp......................	8	90	98	100	98	96.50
2	Brass hand-lamp..................	24	89	98	102	100	97.25
3	Glass stand-lamp	8	88	90	93	94	91.25
4	Glass stand-lamp	11	88	92	94	94	92.00
5	Glass stand-lamp	20	85	92	94	94	91.25
6	Glass stand-lamp	7	90	94	96	93	93.25
7	Glass stand-lamp	10	90	96	96	96	94.50
8	Glass hand-lamp......................	9	88	95	98	98	94.75
9	Glass hand-lamp	6	89	95	96	97	94.25
10	Glass hand-lamp......................	7	88	92	93	94	91.75
11	Brass student-lamp....................	13	89	100	102	102	98.25
12	Glass stand-lamp	10	88	92	93	93	91.50
13	Brass stand-lamp	11	106	114	116	110	111.50
14	Tin lantern..........................	7	99	106	107.	105	104.25
15	Glass bracket-lamp	19	85	92	91	91	89.75
16	Glass stand-lamp	20	86	91	92	92	90.25
17	Brass student-lamp	7	92	99	100	100	97.75
18	Brass student-lamp	14	94	100	100	102	98.50
19	Brass stand-lamp	12	108	112	112	107	109.75
20	Metal stand-lamp	9	91	96	100	99	96.50
21	Brass stand-lamp	12	104	110	108	106	107.00
22	Bronze stand-lamp....................	16	84	90	95	98	91.75
23	Glass hand-lamp......................	6	90	92	94	94	92.50
24	Brass student lamp	10	124	129	129	128	127.50
25	Brass student-lamp	12½	120	126	127	127	125.00

With the air of the room at from 90° to 92° F. the temperature of the oil in the burning lamps ranged from 84° to 129° F., the highest temperature being exceptional.

SYNOPSIS OF THE OBSERVATIONS.

	In 25 lamps.	In 13 metal lamps.	In 12 glass lamps.
	Deg. F.	Deg. F.	Deg. F.
Highest temperature observed.......	129	129	98
Lowest temperature observed.......	84	84	85
Average temperature observed......	98¾	104¼	92⅛

By these results it appears that the temperature of the oil in lamps often rises much above 100° F., thus reaching a temperature at which oil, *which does not emit a combustible vapor below* 100° *F.,* would be dangerous. It is apparent that 100° F. is too low a standard for safety; 120° F. would not be too high a standard, and its adoption would not add three cents per gallon to the cost of the oil.

An analysis of these tables shows that when the temperature of the room was 73° to 74° (a comfortable temperature) only one lamp in twenty-three reached a temperature of 100°, and no glass lamp reached a temperature of 90°, and that the average temperature of the twenty-three lamps was only 83° F. The average temperature of the eleven metal lamps was 5° higher than that of the twelve glass lamps. When the temperature of the room was 82° to 84° (quite warm for comfort) only one lamp in twenty-five reached a temperature of 120°, and only two glass lamps reached a temperature of 90°, the highest reaching 91°. The average temperature of the twenty-five lamps was 91½° F. The average temperature of the thirteen metal lamps was 10¼° higher than that of the twelve glass lamps. When the temperature of the room was 90° to 92° F. (an uncomfortably high temperature) only two lamps out of twenty-five reached a temperature of 120°, and no glass lamp reached a temperature of 100°, and the average temperature of the twenty-five lamps was only 98¾° F. The average temperature of the thirteen metal lamps was 12⅛° higher than that of the twelve glass lamps. Moreover, in the seventy-three lamps tested, but twelve reached a temperature above 100°, and but six above 110°. A series of experiments were described by H. B. Cornwall, (*a*) in 1876, which were made with the design of showing how much naphtha must be removed from a low-test oil to bring it up to safety. His results are tabulated on page 219.

No.	Sp. gr.	Time.	Flashing point.	Time.	Burning point.
	Deg. B.	Minutes.	Deg. F.	Minutes.	Deg. F.
1	49.7	21	86	7	107
2	....	25	96	8	112
3	48.7	....	110	....	124
4	47.1	15	80	7	100
5	45.3	23	121	5	138
6	....	12	98	5	113
7	50.4	23	118	6	135
8	45.8	12	104	5	125
9	....	23	104	5	120
10	....	23	81	....	....

No. 1 was an oil flashing at 86° and burning at 107°. He distilled off 4 per cent., and the residue (No. 2) flashed at 96° and burned at 112°. He then distilled off of another portion of the same oil 10.6 per cent., and the residue (No. 3) flashed at 110° and burned at 124°. On mixing the distillate and the residue in proper proportions the mixture flashed at 89° and burned at 107°, almost at the identical temperatures with the original oil No. 1. An oil worse than No. 1 (No. 4) was then distilled until 12.7 per cent. of distillate was secured with 2.7 per cent. of loss. The residue (No. 5), which was very dark, flashed at 121° and burned at 138°. Five per cent. of distillate was removed from another portion of the same sample, and the residue, after treatment with sulphuric acid and soda, gave No. 6, which flashed at 98° and burned at 113°. The following table embraces some experiments made with mixtures of oils and naphtha, and includes some results obtained by Dr. C. B. White, of New Orleans, Louisiana:

Oils.	Flashing point.	Difference.	Burning point.	Difference.
No. 7. Table I:	Deg. F.	Deg. F.	Deg. F.	Deg. F.
Alone..	118	....	135	....
+ 1 per cent. naphtha of 65° B...........	112	6.0	129	6.0
+ 3 per cent. naphtha of 65° B...........	103	5.0	123	4.0
+ 5 per cent. naphtha of 65° B...........	96	4.4	116	3.8
+10 per cent. naphtha of 65° B..........	83	3.5	102	3.3
+ 1 per cent. naphtha of 71.7° B.........	107	11.0	133	2.0
+ 5 per cent. naphtha of 71.7° B.........	Below 70	....	105	6.0
No. 8. Table I:				
Alone.............	104	....	125	....
+ 2 per cent. naphtha of 65° B	96	4.0	120	2.5
+10 per cent. naphtha of 65° B	76	2.8	107	1.08
Dr. White's oil:				
Alone..	113	....	....	....
+ 1 per cent. naphtha of 65° B...........	103	10.0	....	....
+ 2 per cent. naphtha of 65° B...........	92	10.5	....	....
+ 5 per cent. naphtha of 65° B...........	83	6.9	....	....
+ 10 per cent. naphtha of 65° B..........	59	5.4	....	....
+ 20 per cent. naphtha of 65° B..........	....	....	50	....

The naphtha of specific gravity 65° B. is termed *benzine*, the commercial naphtha having a specific gravity of 70° to 76°. The columns marked "Difference" show the average difference for each per cent. of naphtha added. The naphtha used by Dr. White was lighter than 65° B. A series of experiments was undertaken to show the difference in two consecutive tests for flashing point made upon the same sample of oil, after allowing the oil to cool between the tests. The difference was found to be from 3° to 4°.

Probably the greatest danger from kerosene lamps arises from the risk of overturning and breaking the lamp, although undoubtedly explosions sometimes break lamps. A series of experiments were undertaken with a view to ascertaining the action of oils of different quality under conditions similar to those attending a broken lamp.

Thin glass flasks were provided with corks, through which passed tubes holding wicks. The oil in each flask was then heated in a water bath to 95° F., and the wick lighted, after which the flask was dropped on a brick floor near a steam boiler, the bricks having a temperature of about 93° F. The results are given in the following table. No. 8 was a mixture of No. 1 with 5 per cent. of naphtha of 65° B., and No. 9 of No. 1 with 5 per cent. of naphtha of 71.7° B.; the others were bought from dealers.

No.	Flashing point.	Burning point.	Remarks.
	Deg. F.	Deg. F.	
1	118	135	The wick continued to burn quietly without igniting the spilled oil.
2	104	120	Like No. 1.
3	100	112	Do.
4	98	116	Part of the oil was slowly ignited.
5	96	111	All of the oil at once took fire.
6	80	100	Like No. 5.
7	89	98	Do.
8	93	116	Do.
9	Below 70	105	Ignited with a flash.

From the above experiments the following conclusions may be drawn, as applying at least to these oils:

1. The naphthas distilled were comparatively heavy, 59° to 64° B., technically known as benzines.

2. The removal of about 10 per cent. of these naphthas from an average unsafe oil raised the flashing point 2.27° and the burning point 1.60° F. for each per cent. removed; the addition of the same proportion of naphtha of equal specific gravity lowered the flashing point in very nearly the same ratio.

3. The second table shows that a paying amount of a light naphtha above 70° B. could not be added to even a very high grade oil without making it conspicuously bad, while as much as 10 per cent. of a heavier naphtha (benzine) of 65° B. could be added to an oil of a little above 100° F. flashing test, and make it no worse than much of the oil now in the market.

4. When a small amount of naphtha of above 70° B. is added to a good oil the flashing point is lowered much more rapidly than the burning point; if the oil is of very high grade and the naphtha moderately heavy, 65° B., the burning point of the oil is lowered almost as rapidly as the flashing point, while the addition of a naphtha of 65° B. to a moderately good oil, flashing at 104° F., lowers the flashing point 35 to 40 per cent. more rapidly than the burning point.

5. The burning point is not a reliable test of the safety of an oil, since oils, when spilled, will ignite instantly on the approach of a flame when heated a degree or two above their flashing point, even although the burning point is 10° or 20° F. higher. (a)

6. The first two tables show that an oil flashing at 86° and burning at 107° F. can be made to flash at 100° by removing 6 or 7 per cent. by distillation. This corresponds nearly with the estimate * * * that average petroleum yielding 75 per cent. of 110° F. "fire test" (burning test) oil would probably yield 69 per cent. of 100° "flash oil"; in other words, 8 per cent. of the 110° "fire test" oil would have to be removed to make a 100° "flash" oil. The average flashing point of eight oils given in Dr. Chandler's report as burning at 110° F. was 89°. (b)

These conclusions were stated with equal emphasis by Dr. Chandler in his report, from which I have already quoted. He says:

There are two distinct tests for oil: (1) *the flashing test*, (2) *the burning test*, which are often confounded; and when the law or ordinance specifies the *fire test* there is a doubt as to which of the two tests is intended. *The flashing test* determines *the flashing point* of the oil, or the lowest temperature at which it gives off an inflammable vapor. This is by far the most important test, as it is the inflammable vapor, evolved at atmospheric temperatures, that causes most of the accidents. Moreover, an oil having a high flashing test is sure to have a high burning test, while the reverse is not true. *The burning test* fixes the burning point of the oil, or the lowest temperature at which it takes fire. The burning point of an oil is from 10° to 50° F. higher than the flashing point. The two points are quite independent of each other; the flashing point depends upon the amount of the most volatile constituents present, naphtha, etc., while the burning point depends upon the general character of the whole oil. Two per cent. of naphtha will lower the flashing point of an oil 10° without materially affecting the burning test. The burning test does not determine the real safety of the oil; that is, the absence of naphtha. The standard which has been generally adopted as a safe one fixes the flashing point at 100° F. or higher, and the burning point at 110° or higher. In the English act and some of * * * the laws of the states of the American Union the burning test has been very judiciously omitted, as two distinct tests are often confusing; and, moreover, the burning test or point is not an index of the safety of the oil. More than half of all the samples of oil which have been tested for the health department (of New York city) did not take fire below 110° F.; consequently they were safe according to the burning test; but only twenty-eight of seven hundred and thirty-six samples w really safe, all the rest evolving inflammable vapors below 100° F. *The flashing test* should therefore be the only test mentioned in laws framed to prevent the sale of dangerous oils. (c)

In 1873 a committee of the Franklin Institute, of Philadelphia, reported "On the causes of conflagrations and the methods of their prevention". This committee reported that in 1872 the number of fires occurring in Philadelphia was 41¼ per cent. greater than in the previous year. Of these fires, 59 (the largest number originating from any one source) were caused by explosions of coal-oil and fluid lamps. The report further states:

The number of deaths in the United States from the explosions of coal-oil and fluid lamps in 1871 was, by the account kept by an insurance paper (the *Chronicle*), 3,500. If the death rate for 1872 kept pace with the increase of conflagrations, which was about 50 per cent., it would give for the past year (1872) 5,250 deaths, and the maiming of probably 20,000 persons within the jurisdiction of the United States.

Statistics of this character could be extended indefinitely.

Regarding the nature of petroleum products, this committee report:

We find by actual experiments that all the light forms of petroleum (products) constantly generate vapor or gas even at the low temperature of 12° above zero. * * * Any oil or burning fluid that evaporates rapidly or generates gas below 100° is exceedingly unsafe. * * * It is not the oil or fluid that explodes, but the vapor mixed with air. * * * When the mixture goes on so that there is one part of gas and four parts of atmospheric air inside the lamp, or when these proportions exist in a room or any other apartment, they form a fearfully explosive mixture. * * * Volatile oils and combination burning fluids generate vapor inside the lamp, hence the less the oil the greater the vacant space filled with vapor and atmospheric air and the greater the danger, and hence it is apparent that to fill a lamp nearly empty while burning is almost certain to result in a terrific explosion.

This report was accompanied by another, in which the subject was discussed by the then secretary of the institute, William H. Wahl, esq. In this report Dr. Wahl reviews the subject in great detail, and reaches the same conclusions as Dr. Chandler, above quoted. (d)

I have already referred to the elaborate research of Dr. J. Biel, of Saint Petersburg, upon the comparative value of American and Russian petroleum, published in Dingler in 1879. (e) After reviewing the comparative production of America and Russia, in which he shows that the average yearly yield of a Caucasian well is three times as great as that of an American well, he refers to the "special general meeting of the Petroleum Association" held in London on the 14th of January, 1879, at which Mr. F. W. Lockwood, of New York, was present, and the representations there made, that the illuminating oils produced from the petroleum of the Bradford district were not of the same

a See in this connection Chandler's report, *Am. Chem.*, iii, 42.

b *Am. Chem.*, vi, 458.

c *Am. Chem.*, iii, 42; *Mon. Sci.*, 1872; Dingler, ccv; W. B., 1872.

d *Jour. Frank. Inst.*, xcv, 267.

e Dingler, ccxxxii, 354.

quality as those exported from the United States in previous years and manufactured from the petroleum of the Parker (Butler and Clarion) district. He then goes on to say that the American oils offered for sale were very inflammable and were deficient in illuminating power; that they burned well for a few hours, and that during the succeeding hours, in order to maintain the illumination, it was necessary to raise the wick at short intervals, the result of which was finally the accumulation of carbon upon the wick. In order to determine the cause of this trouble Dr. Biel selected three American kerosenes, Pratt's astral oil, and several specimens of Russian kerosene, and subjected them to fractional distillation in a glass retort with a thermometer immersed in the oil. That portion distilling below 150° C. (302° F.) he called *essence* (essenzen); that portion coming over between 150° and 270° (518° F.) he called *burning oil* (brennöle); and that above 270° he called *heavy oil* (schwere Oele). The three American kerosenes were *Carbon oil* of the Standard Oil company, of Cleveland, Ohio; *Standard oil* of the Imperial Refining Company, of Oil City, Pennsylvania; and *Standard White*, of unknown manufacture. The three oils gave practically the same results, as follows:

1. *Standard oil*, specific gravity 0.795, flash point 26° C. (78° F.), burning point 30° C. (86° F.); concentrated sulphuric acid in equal parts with the oil is colored blackish brown upon being shaken with it. Tension of vapor according to Salleron, 160mm at 35° C. The distilled products were:

Temperature.	Per cent.	Specific gravity.	Burning point.	
Deg. F.		*Deg. B.*	*Deg. C.*	*Deg. F*
(a) 125 to 150	14.4	0.741 = 59	16	(162)
(b) 150 to 170	9.8	0.760 = 54	29	(85)
(c) 170 to 190	8.3	0.770 = 52	43	(110)
(d) 190 to 210	6.0	0.778 = 50	59	(140)
(e) 210 to 230	5.6	0.786 = 48	75	(167)
(f) 230 to 250	8.6	0.796 = 46	100	(212)
(g) 250 to 270	7.6	0.808 = 43	112	(233)
(h) 270 to 290	5.8	0.818 = 41	....	
(i) Residue ...	33.9	0.840 = 37½	....	

I have given the equivalents of the specific gravity and temperatures in degrees of Baumé and Fahrenheit.

The distillation was accompanied with a copious evolution of sulphurous acid and the distilled products that come over between 190° and 230° C. (374° to 536° F.) are also strongly impregnated with it. This is produced by the decomposition of the sulphur compounds in the kerosene, which are produced by the reaction of the crude distillate with the concentrated sulphuric acid, with which the American kerosene is imperfectly purified. He summarizes his results obtained from the three Standard oils as follows:

14.4 per cent. light inflammable essence.

45.9 per cent. really good burning oil.

39.7 per cent. heavy oil.

2. *Astral oil* or so called, "150° fire test," specific gravity 0.783, flashing point 48° C. (118° F.), burning point 51° C. (124° F.). Shaken with an equal quantity of concentrated sulphuric acid it is colored a golden yellow. Tension of vapor after Salleron, 5mm at 35°. The distilled products were:

Temperature.	Per cent.	Specific gravity.	Burning point.	
Deg. F.		*Deg. B.*	*Deg. C.*	*Deg. F.*
(a) Under 150	2.2	....	16	(62)
(b) 150 to 170	13.5	0.758 = 55½	29	(85)
(c) 170 to 190	21.3	0.768 = 52	43	(110)
(d) 190 to 210	18.8	0.777 = 50	57	(133)
(e) 210 to 230	15.0	0.786 = 48	75	(167)
(f) 230 to 250	10.0	0.795 = 46	99	(210)
(g) 250 to 270	9.2	0.806 = 44¼	111	(231)
(h) 270 to 290	4.8	0.813 = 42	....	
(i) Residue....	5.2	0.834 = 38	....	

The distillation was entirely destitute of any deleterious odor, and the distillate was normal throughout. He summarizes his results as follows:

2.2 per cent. light inflammable essence.

87.8 per cent. good normal burning oil.

10 per cent. heavy oil.

The results that he obtained from the examination of the Imperial oil (Kaiseröl) of Aug. Korff of Bremen, were nearly identical with those obtained from the astral oil, and his examination of the several samples of Russian oil showed them to be of very fair average quality. (a)

a See page 180. A better method of conducting a research of this character is to use alembics instead of retorts; 200 cubic centimeters in an 8-ounce alembic will yield 1 per cent. for every 2 cubic centimeters of distillate. If the distillate is received into a narrow measuring jar graduated to one-half cubic centimeters, the measuring can be made to one-fourth per cent. without difficulty.

The point in this discussion emphasized by this research is to be sought in the character of the 14.4 per cent. of distillate obtained from the American kerosenes below 150°, having a specific gravity of 59° B. and burning at 62° F. This naphtha, more dense than average benzine, when mixed with a residue containing oils more dense than those found in the astral oil, produces an oil flashing at 78° and burning at 86°, an extremely dangerous oil if no consideration were made of the large content of sulphur compounds revealed upon distillation. These kerosenes were *cracked oils*, not mixed "tops and bottoms", as the English oil merchants have styled them, but a cracked product that was run for a given specific gravity (0.795, equal to 46° B.) and color, without much regard to test, and none at all for other considerations. While there are, no doubt, occasional instances in which retail dealers have mixed naphtha with good kerosene for purposes of fraudulent adulteration, I do not believe that oils are thus prepared by either wholesale dealers or manufacturers. It is, however, not to be denied that the temptation is very great for manufacturers to allow too large a proportion of benzine for safety to run into an oil designed for a market where there are no laws prohibiting the sale of such substances. It is more probable that these kerosenes were made, as Dr. Biel received them, by cracking the heavy residue from which the normal burning oil had been previously removed, a part of which had been cracked too much and the remainder too little, than that the heavy and light residues, once separated, had been mixed together.

Dr. Chandler is at some pains to show that a cost of a few cents per gallon will remove the naphtha from dangerous kerosene. When kerosene sells at wholesale for less than seven cents a gallon, a few cents a gallon would be a large per cent. of its value. *What per cent. of the present price of refined petroleum would be required to place all of the oils sold at a flash test of 100° F., and of good quality as regards color and sulphur compounds,* I am not able to say. I have not the least doubt, however, that it is quite impossible to convert Bradford oil, with all its paraffine, into illuminating oil of good quality in *all respects* by one distillation and one treatment unless the whole distillate below 60° B. is run into burning oil. I am quite certain that it is impossible to crack the heavy residue from which the normal burning oil that exists in the petroleum has been run off and produce a good oil by one distillation and one treatment, nor do I believe that such an oil can be made safe, that is, with a *flash* test of 100°. The question of how much additional expense would be involved in rendering oils prepared by one distillation safe involves quite a radical change in the manufacture of these oils; a change that would, of necessity, increase the cost of the oils, and would, therefore, have to become universal, but which would not necessarily render the manufacturer's profit less certain. At the same time it would improve the quality of the oils to the manifest advantage of the consumer in respect to safety, health, and economy. That poor oils are not safe has been fully proved; that they are not healthful is as clearly proved by the vapors of sulphurous acid and the products of imperfect combustion from crusted wicks and imperfect flow of the oil. Dr. Beil says, when commenting upon the three samples of American kerosene examined by him:

It is apparent that a kerosene containing such a quantity of heavy oil, and that in addition to this is contaminated by tarry substances containing sulphur, cannot possibly satisfy the demands of the public. While the heavy oils are not in a condition to ascend to the flame in sufficient quantity, the carbonized tarry substances obstruct the wick and prevent the further ascent of the kerosene to the flame. (*a*)

That they are not economical is further shown by the research of Dr. Beil, in which the illuminating power of these common oils is compared with astral oil with the following result:

ILLUMINATING POWER AT A LEVEL DISTANCE OF—

		6cm.	9cm.	12cm.	14cm.
Standard		7	3.35	1.36	0.80
Astral		7	4.50	3.00	1.36
Imperial		7	6.00	3.00	1.36
Russian	(o)	7	6.25	4.45	3.70
Russian	(a)	7	5.20	4.00	3.00
Russian	(b)	7	5.70	3.20	1.65
Russian	(c)	7	...	...	...

At 6cm the oils are equal; at 9cm the astral oil is 34 per cent. better than the kerosene; at 12cm the astral is 120 per cent. better than the kerosene; and at 14cm. the astral is 70 per cent. better than the kerosene. The average value of the astral for that distance above that of the kerosene is 27½ per cent. In addition to the inferior illuminating power of these inferior oils we have the fact that they are consumed more rapidly. I am not aware that any exact determinations have been made respecting the comparative rapidity with which equal quantities of these oils are consumed, but it is undoubtedly a fact that oils containing a large proportion of benzine are consumed much more rapidly than those that consist of what Dr. Biel calls "normal burning oils".

I am informed that the demand for "high-test" oils is not equal to the amount that can be made from the petroleum manufactured. Manufacturers the world over can only make what they can sell, and the ignorant and

a Dingler, ccxxxii, 357.

reckless buy the cheapest oil, regardless of all other considerations, encouraging the production of these cheap oils. It is here that intelligent legislation is required, to protect the ignorant purchaser on the one hand, and the honest manufacturer from unprincipled competition on the other, as well as the innocent public, especially prominent as women and children, from the consequences that follow the use of dangerous oils; not safe even with patent " safety lamps ". As Dr. Chandler said ten years ago :

It is not possible to make gasoline, naphtha, or benzine safe by any addition that can be made to it. Nor is any oil safe that can be set on fire at the ordinary temperature of the air. * * * Even when the " safety lamp " has an ally in the form of a " safety can ", it still fails to make naphtha safe. It is an axiom that no lamp is safe with dangerous oil, and every lamp is safe with safe oil. * * * What we want is safe oil; with it all lamps will be safe. (a)

This axiom expresses a permanent truth. The legitimate use of naphtha for illuminating purposes will be further discussed in Chapter III.

Referring to page 218, it will be observed that Dr. Chandler concludes, from his experiments upon the temperature of the oil in burning lamps, that " it is apparent that 100° F. is too low a standard for safety; 120° F. would not be too high a standard ".

While it cannot be denied that these conclusions are correct as indicating a standard of absolute safety, it will be observed that in these experiments the extreme temperature of oil in glass lamps was 98°, being never over 8° above the temperature of the room. The higher temperatures were in metallic lamps, in which the oil reached 27°, and in one instance 39° above the temperature of the room, the exceptional temperature being reached by student-lamp No. 24. Metallic lamps are widely but not generally used, and student-lamps are so constructed as to reduce the danger of explosion to a minimum. It therefore appears to me that if legislation strictly required all oil to be brought to a *flash test* of 100° F. the general public would be fairly protected in the legitimate use of such oils, so far as mere legislation alone can afford protection. Such legislation should rigidly exclude all forms of naphtha from use in households, in lamps or in stoves of any pattern whatever, as always, under all circumstances and under whatever name or guise, more dangerous than gunpowder. An oil that will not take fire when thrown from a lamp broken upon a brick floor heated to a temperature of 93° is a safe oil for legitimate use. Floors are rarely heated to that temperature. A temperature to which oil is heated in lamps of *ordinary* construction in a room the atmosphere of which stands at 93° is a safe temperature. An oil that did not reach 100° under the last conditions stated, and that did not take fire under the first conditions stated, flashed at 100°. I therefore conclude that an oil that flashes at 100° F. is a safe oil, and while oils that flash at a higher temperature, and *that cannot be prepared by cracking petroleum by one distillation*, are more safe, healthful, and economical, legislation can hardly require anything further than a reasonable limit of public safety.

SECTION 3.—METHODS OF TESTING PETROLEUM.

I have not been able to ascertain where, when, and by whom the question of safe oils was first agitated. Early in 1861, when I was engaged in examining petroleum in the laboratory of Brown University, Professor N. P. Hill (now Senator Hill, of Colorado) was interested in this subject, and it was with his assistance, if not at his suggestion, that the experiments described in Mr. Allen's paper, previously quoted, were undertaken. The method of conducting the test, as described by Mr. Allen, was at that time supposed to be sufficient, and it is my belief that when undertaken by a careful manipulator, accustomed to the use of apparatus, it is; but it soon after became apparent that in untrained hands this method of manipulating was in many respects deficient. As a result, a large variety of apparatus and of methods have been contrived for testing oils, both in America and in Europe. The following descriptions of several testers, that represent the classes to which they belong, are taken from an elaborate article in the *Sanitary Engineer*, abridged from the article of Messrs. Engler and Haas in the *Zeitschrift für Analytische Chemie*, 1881: (b)

Petroleum testers may be divided into two classes, according to the principle upon which they are constructed. In the first class, the vapor expansion of the petroleum is measured at a stated temperature, and from this its combustibility ascertained; while in the second class the temperature is determined at which the oil evolves inflammable vapor. To the first class belongs the apparatus of Salleron-Urbain, which is the most accurate of its kind, and the only one to be described. Most testers belong to the second class, and are known as " opened " or " closed ", the latter because the surface of the oil is more or less protected from the atmosphere.

In some countries two points are determined in testing petroleum: the first is that of the temperature at which the liquid begins to give off an inflammable vapor, and is known as the "flashing point"; while the second, or "burning point", is the temperature at which the liquid continues to burn when ignited. Most forms of apparatus are constructed with reference to the determination of the flashing point only, and, as an oil becomes dangerous at the temperature of its flashing point, there is no necessity for a further test.

The flashing point of a petroleum will be found to vary according as the vessel is partly or entirely filled with petroleum, is open or closed, the petroleum is quiet or agitated, whether the air above it is in a large or small volume in relation to the quantity of oil, whether quiet or in motion, whether charged more or less with the vapor evolved from the petroleum, and, above all, as to the distance of the torch from the surface of the oil. It is also necessary to consider the kind and size of the taper used, the length of time it is allowed to remain near the surface of the oil in applying a test, the dimensions and material of the oil-holder, and the rapidity and uniformity of heating. As these conditions vary in different forms of apparatus, the flashing point will be found higher or lower; and even in the same apparatus this may happen, according to the care given to the manipulation in the above respects.

Salleron-Urbain's apparatus, in which the expansion of the vapor of petroleum is determined, is used principally in France. It consists of a copper vessel, A, Fig. 48, in which is fixed the conical pillar D, and which is covered by the plate *d d* fitting on its upper edge. C is a movable plate turning on the pillar D, and held in place by the screw *n*. In this movable plate is the cylindrical chamber

B, closed at the top by the screw-plug p, while its lower opening can be placed in communication with the vessel A by means of the opening o, or by turning the plate C it can be sealed by the upper surface of d. There are also in the plate d a thermometer, a graduated tube m, 35^{cm} long, and the regulating apparatus l, which consists of the screw r, so arranged that by raising or lowering it the water level in m is made to stand at zero.

Fifty cubic centimeters of water are put in the vessel A, the plate d d and the sliding piece C are screwed down tight by n and so placed that the chamber B does not communicate with A. B is nearly filled with the petroleum to be tested, the screw p replaced, and the whole placed in warm water until the temperature has become constant. The water level in m is placed at zero, and then the plate C is moved until the opening of B comes over the opening o. The petroleum spreads upon the surface of the water in A, and by the expansion of its vapor causes the water to rise in the tube m, when its height is read. By a comparison of this number with the known expansion of the vapor of normal petroleum at a corresponding temperature the combustibility of the oil is determined. For this purpose a table accompanies the apparatus which gives the obtained vapor expansion of normal petroleum in m for different temperatures sought.

This method depends upon the supposition that the numbers which express the expansion of the petroleum vapor run parallel with the temperature of the inflammability of all kinds of petroleum. It has been found, however, that this supposition is not correct for all cases, inasmuch as the presence of a small quantity of a very volatile hydrocarbon occasions, by increased temperature, a correspondingly greater pressure in the tube m, without its being sufficient to form an explosive mixture with air. Experiments were made on samples of petroleum prepared by mixing in varying proportions oils of low and high boiling points, and from these experiments it is concluded that a small percentage of a volatile constituent, notwithstanding the equal inflammability of the oils, occasions an uncorresponding increase of the vapor expansion. From this it is evident that while this form of apparatus would give accurate results in some cases, it could not be depended upon in others. They have concluded that oils are to be considered safe that exhibit a tension of 64^{mm} of water at 35° C.

The second class of petroleum testers are designed for the determination of the "flashing point", or temperature at which the oil gives off an inflammable vapor. The majority of testers, and those found most reliable, belong to this class.

The older forms consisted of an open vessel partly or entirely filled with petroleum, and heated until inflammable vapors were formed upon the surface of the oil. These have been improved by placing the petroleum in a closed vessel, by which the conditions of the actual use of the oil in lamps is more nearly attained.

Of the open testers the Tagliabue, the Danish, and the Saybolt are the most important.

Tagliabue's open tester, Fig. 49, was employed in the official testing of petroleum in this country until 1879, and even now it is used in Germany with immaterial changes and under various names. It consists of a brass water-bath A upon the stand B, heated by the lamp C. D is the glass petroleum-holder, in which is immersed the thermometer E. The bath is nearly filled with cold water, allowing for the displacement by the oil-holder. D is filled to the top with the petroleum to be tested, care being taken not to wet the rim, the thermometer placed in position, and the lamp lighted. The heating should be gradual, and, if necessary, the lamp be occasionally removed. When the oil has reached the temperature at which you wish to begin the testing, a small flame, either from a wooden splinter or a gas jet, is slowly and carefully passed over the petroleum, about 12^{mm} (nearly half an inch) from its surface. If no flashing takes place, this is repeated as the temperature rises until the flashing point is reached. During testing the apparatus should be protected from draughts of air.

The Danish tester differs from Tagliabue's only in having the petroleum vessel of copper instead of glass, and in being but partly filled with oil.

The Saybolt tester was, in 1879, adopted by the produce exchange of this city in the testing of refined petroleum. It resembles the open tester of Tagliabue, differing only in the use of the electric spark for the burning splinter. It is represented in Fig. 50, and consists of the copper water-bath F, containing the petroleum-holder, which, with the other parts of the apparatus, are placed on the tray C, and for transportation can be inclosed in the box A. D D are the covers of two battery elements. H is a current breaker, E an induction coil, and e e the conducting wires for producing the spark over the surface of the petroleum. a is the thermometer of the oil-holder, and a¹ that of the water-bath.

In using this apparatus the bath is filled with water and heated to 100° F., after which the lamp is removed. The oil-cup, filled to within 3^{mm} (⅛ of an inch) of the top with the petroleum to be tested, is placed in the bath and the thermometer immersed in the oil until the bulb is just covered. As the temperature of the oil is raised to 90° F., produce a spark by the key H, and after replacing the lamp repeat this operation every two or three degrees until the flashing point is reached.

The apparatus of Abel, represented in Fig. 51, is employed in England in determining the flashing point of petroleum. It consists of the copper cylindrical vessel D, in which is the water-bath, composed of the two copper cylinders B B and C C, the latter resting on the ring g g and covered by the plate K K; f is a funnel for filling the water-bath, and e is the thermometer placed in it.

The brass petroleum-holder A rests in an ebony ring fixed in the plate K, and hangs in the air-filled space H of the water-bath. It is provided with a closely-fitting cover, through which passes the thermometer b, and upon which is placed the small oil-lamp c, movable upon the horizontal axis. There are also in the cover three rectangular openings, which can be opened and closed by the sliding bar d, by the movement of which the lamp is so tipped that its nose comes opposite to the opening in the middle of the cover.

The oil-lamp can be replaced by a gas flame, which is much cleaner, and was used in the experiments with this apparatus.

The water-bath is filled and heated to 54° C. A is then filled to the mark a with the petroleum to be tested, covered and placed in the space H. The wick of the lamp is arranged to give a flame 4^{mm} long. When the temperature, by the thermometer b, has risen to 19° C., the tests are commenced, and repeated every degree or two until the flashing point is reached. In testing very volatile oils the air-space H should be filled with cold water, and in the testing of oils of high flashing point this water should be heated to about 50° C.

In closed petroleum testers the oil is heated in a closed vessel until inflammable vapors rise from the oil into the empty part of the holder. There are a large number of these testers; among them those of Tagliabue, Abel, Sintenis, Parrish, Bernstein, and others.

The Tagliabue closed tester is represented in Fig. 52, and consists of the water-bath A and the petroleum holder B, both of brass. The latter is provided with a cover, upon which are fixed the hood C, containing a rectangular opening a, the sliding bar b, for opening or closing the aperture beneath it, and lastly the thermometer D.

There is also an improved form of this tester differing from the first in the arrangement of the cover, which is shown in Fig. 53. In this a a is the cover, with openings under the movable bar b b, by which they are closed; f f are small openings in b b, closed by the piece e, held up by the spring beneath it. By pressing upon the knob o the apertures f f are opened, and the bar b b can be moved by the handle g.

In using the apparatus, the water-bath and oil-holder are filled and the bath gradually heated by the spirit-lamp. When the thermometer reaches a definite temperature a small flame is introduced through the opening a into the hood C; and at the same time the bar b, in Fig. 52, is moved to one side, or, as represented in Fig. 53, the knob o is pressed down, in order to establish communication with the air by openings b b or f f. This testing is repeated as the temperature rises until the flashing point is reached.

The next petroleum tester to be noticed is the Parrish naphthometer. It is used chiefly in Holland, and differs from those already described in that the inflammable mixture is carried out of the petroleum holder to a stationary flame. It is represented in Fig. 54, in

which A is the tin oil-holder, C the water-bath, D the support, and E the lamp. The holder is provided with a projecting cover, in which is the cylinder d, having in its axis a small tube, with a wick running into the petroleum. e is a screen, against whose base rests the glass plate f for protecting the thermometer from the heat of the wick flame, and lastly B is a chamber communicating with the air, in which are the openings a and b b, the former for the circulation of the air through the petroleum-holder, and the latter to allow the passage of the oil from B into A. The thermometer c is placed in the vessel B.

The bath is filled with cold water, and the oil-holder with the petroleum to be tested, to a point 1^{cm} below the rim. The heating must be slow and effected by the spirit-lamp, whose flame is only 1 to 1.5^{cm} high. The small wick in d is then lighted, care being taken that the flame is not more than 6 to 7^{mm} high. The heat of this flame produces a current of air, which, coming in through the opening a, spreads over the surface of the oil and passes out by the tube d, taking with it the vapors evolved from the heated oil. When the oil vapors are sufficient in amount to produce an inflammable mixture, they are ignited by the flame in d, the flame being extinguished by the sudden motion of the air. At this moment the flashing temperature is read.

The apparatus devised by Engler is of the closed form, to which is added an electric mechanism similar to that of the Saybolt tester. It is shown in Figs. 55 and 56, and consists of the copper water-bath A, heated by the spirit-lamp B. C C is a glass vessel for water, which has a filling mark etched upon it; m m is the cover, and n the thermometer. In the cover is the glass petroleum vessel D, also provided with a filling mark, and to which is fitted the brass cover o o. The latter is shown in Fig. 56, in which will be noticed the following details: s s are two movable covers, t t the conducting wires, insulated by the ebony rings u u, r the thermometer, and q the handle of the stirrer p, seen in Fig. 55. The conducting wires terminate in platinum points in the vessel D, from $\frac{1}{4}$ to $\frac{3}{4}$^{cm} above the surface of the oil, and at a distance of 1^{mm} from each other. For the production of the electric spark a chromate cell is used, with an induction apparatus which gives a spark at least 2 to 3^{mm} long. The electric apparatus of the Saybolt tester answers very well. In using this tester the baths A and C are filled with water, and D is filled to the mark with the oil to be tested. When the petroleum vessel is in place the water in C should stand 1^{cm} below the rim. The wires are connected with the induction coil and the lamp lighted. As the temperature rises to the testing point the spark is passed every degree, care being taken that the spark continues from one-half to one second. After each passage of the spark the oil is gently agitated by the stirrer. The operation is continued in this way until an explosion occurs, by which the covers s s are thrown open.

The difficulties that have been found to attend the construction of an apparatus that in every one's hands should give uniform results have been considerable. In the experiments of Engler and Haas three kinds of petroleum were employed in testing the various forms of apparatus, and at the start the flashing point of each oil was carefully determined in a closed apparatus.

Sample A flashed at .... 22° C. = 71.6° F.
Sample B flashed at .... 29° C. = 84.2° F.
Sample C flashed at .... 40° C. = 104° F.

The following table shows the temperatures at which they flashed in the testers named:

Tester.	A.	B.	C.
	Deg. C.	Deg. C.	Deg. C.
Tagliabue, open.............	22.7 to 38.8	32.2 to 48.8	45.5 to 57.2
Danish	19.5 to 21.0	29.0 to 31.0	42.0 to 45.0
Saybolt.....................	30.6 to 31.7	36.1 to 36.6	48.8 to 52.7
Tagliabue, closed...........	....	24.0 to 39.4	... .
Abel	16.0 to 17.1	22.2 to 23.8	32.4 to 33.8
Parrish	20.7 to 23.0	25.5 to 30.7	36.5 to 39.0
Engler	21.0 to 22.5	28.0 to 30.5	39.3 to 39.7

The average of the several tests with the different instruments on the same samples are given in the following table:

Testers.	No. of tests.		Average.	Variation.
			Deg. C.	Deg. C.
Tagliabue, open..........	A	6	30.95	16.1
	B	9	42.00	16.6
	C	6	52.20	13.3
Danish, open	A	5	20.80	3.5
	B	4	30.00	2.0
	C	4	43.25	3.0
Saybolt, open	A	4	31.30	1.1
	B	2	36.35	0.5
	C	2	50.75	3.9
Tagliabue, closed	B	18	31.68	15.4
Abel, closed.............	A	4	16.60	1.1
	B	7	22.64	1.6
	C	3	32.96	1.8
Parrish, closed	A	5	21.40	2.7
	B	15	27.30	5.2
	C	9	37.70	2.5
Engler, closed	A	4	21.95	1.5
	B	19	29.40	2.5
	C	2	39.50	0.4

The great variation in the results given by Tagliabue's open tester were due to a variation in the height at which the flame was passed above the oil, and the temperatures indicate different heights, from 1ᵐᵐ (0.04 of an inch) to 12ᵐᵐ (0.47 of an inch).

The uniformity of the results furnished by Engler's apparatus upon sample B, where eleven out of nineteen tests were within a variation of 1° C. and sixteen out of nineteen tests were within 1.5° C., is quite remarkable, and shows that this apparatus is greatly superior to most of the others in this respect.

By the use of the double water-bath and the stirrer the heating is slow and regular, and, so far as possible, is independent of the size of the heating flame. Moreover, by the use of the electric spark, the size, intensity, and distance of the igniting agent is always the same, and in consequence of its short duration no vapor formation is noticeable. Finally, the form of this tester is such that the conditions maintained in its use closely resemble those which are found to exist in petroleum lamps. Herr Victor Meyer is of the opinion that, in the use of the ordinary petroleum testers, the true or absolute flashing temperature of the oil is not found, but a temperature higher or lower than the one sought, depending upon the capacity of the various forms of apparatus and the quantity of petroleum employed. The progress recommended consists in putting about 40 cubic centimeters of the petroleum in a glass cylinder of about 200 cubic centimeters capacity, and placing this in a vessel of warm water until the petroleum has reached the testing temperature. The cylinder is then removed, and the oil well shaken; after which a test is made by means of a gas flame, to see if the oil can be lighted. It is clear that in this process we obtain a constant maximum of the saturation of the oil with petroleum vapor corresponding to the prevailing temperature.

In this country the open tester of Tagliabue was at first in general use, and later his closed tester. The New York produce exchange has, within a few years, adopted Saybolt's. In England and Canada Abel's has been adopted; in France both open and closed testers, particularly the tester of M. Granier, has been used, as well as the apparatus of Salleron Urbain; in Holland the naphthometer of Parrish; and in Russia, and also in Germany, some of the open testers have been employed.

It is manifest that the great difference in the results given by these instruments, included between 22.64° C. and 42° C., when made by the same person on the same oil, indicates that a decision should first be had in respect to the instrument used before the temperature should be determined at which an oil is considered safe.

I think that more attention has been paid to this subject in England than in this country, or it would perhaps be more proper to say that in England the subject has received consideration in a manner that has produced more satisfactory results. There legislation has been national; here it has been local. There the subject was placed in the hands of eminent scientific men, and legislation was had in 1868 based upon the results of their labors. This legislation described the instrument and the manner of testing, and fixed the test at a flash at 100° F. After a trial of two years, during which numerous criticisms were found to lie against the provisions of the law, Professor F. Crace Calvert subjected the working of the apparatus under the act to very careful examination, and concluded (a) that—

These results show the influence of time in raising six samples of petroleum spirits from 52° F. to their flashing points. Thus, when fifteen or twenty minutes are employed, the whole of the six samples tested could not be called "petroleum", according to the act of 1868; the owner would be liable to a penalty and the loss of the fluids, whilst if the time employed to heat the liquid is half an hour they would all be considered petroleums, their flashing points being above 100° F.

His results are given below:

FLASHING POINT.

No. of sample.	Time, 15 minutes.	Time, 20 minutes.	Time, 30 minutes.
	Deg. F.	Deg. F.	Deg. F.
1	96	98	102
2	92	99	101
3	90	98	101
4	94	96	104
5	90	98	110
6	95	99	108

He further remarks on this point:

I am therefore of opinion that as the act has been made to protect the public from fire and explosions resulting from the employment of too highly inflammable hydrocarbons, the chemist or person called upon to test liquids of this class should raise the temperature of the fluids as quickly as possible; otherwise they favor the vendor and manufacturer, to the detriment of the consumer.

The next series of experiments was made with a view of corroborating a statement made by Mr. Norman Tate, viz, if two thermometers are placed in the petroleum spirit, one, as indicated in the act, 1¼ inches below the surface of the liquid, the other being only one-half inch below the surface, a difference of several degrees will be noticed between them at the time the vapors will flash. * * * The following results confirm Mr. Tate's observations:

	Flashed at—	Flashed at—
No. 4	94° F. 1¼ inches.	99° F. ½ inch.
No. 5	94° F. 1¼ inches.	98° F. ½ inch.
No. 6	95° F. 1¼ inches.	99° F. ½ inch.

This curious and unusual fact is due, in my opinion, to this: that petroleum not being a homogeneous liquid, but a mixture of several hydrocarbons, the highest products being first expelled, the heat rises toward the surface, and in this way the difference in temperature referred to is produced.

After suggesting a remedy for these difficulties Professor Calvert closes his article as follows:

From the above experiments the following conclusions may be drawn, viz, that the petroleum act of 1868 does not give sufficient and precise instruction for testing petroleum spirit; therefore it is to be hoped that government will take the matter in hand and do away with the objections to the present act, substituting more clearly defined rules and instructions, so as to enable the operator to determine the flashing point of petroleum spirit with greater accuracy.

This subject was again very fully discussed by Mr. Boverton Redwood, secretary of the Petroleum Association of London, in 1875, (a) in a letter to the *English Mechanic and World of Science*, in which he gives a very excellent popular description of the manner of testing petroleum under the petroleum act then in force.

In July, 1875, the Secretary of State for the Home Department requested Professor F. A. Abel, chemist to the War Department, to report on certain points relating to the method of testing petroleum as prescribed in Schedule 1 of the petroleum act, 1871. In accordance with this request he submitted his report, dated August 12, 1876. Before commencing his investigations he consulted, among others, the late Dr. H. Letheby, Dr. J. Attfield, Dr. B. H. Paul, and Mr. Boverton Redwood, representing with himself an unsurpassed array of talent and experience with reference to this subject. I quote here this report entire as representing the most complete and intelligent discussion of this subject extant, based upon a most exhaustive scientific research, and confirmed by comparative tests in such a manner as to make it a model for a basis of intelligent legislation.

REPORT TO THE SECRETARY OF STATE FOR THE HOME DEPARTMENT ON THE SUBJECT OF THE TESTING OF PETROLEUM.

In compliance with the request of the Secretary of State for the Home Department, as conveyed by Home Office letter, dated July 7, 1875, 1,386, 61 a, Appendix V, that I should report on certain points relating to the method of testing petroleum as prescribed in Schedule 1 of the Petroleum Act, 1871, I now submit the following statements and the conclusions at which I have arrived respecting the points specially submitted for my consideration in the letter above referred to:

I.

With reference to the merits of the method of testing petroleum at present prescribed.

In the evidence taken before a Select Committee of the House of Lords in 1872, the relative merits of and the relation existing between the open flashing test which is prescribed in the existing petroleum act and a modified flashing test, called the "close test", which it was proposed to substitute for the former, were discussed by a number of witnesses.

The opinions expressed and the experimental data upon which the opinions were based were in several respects very conflicting.

The statements of a great majority of the witnesses were, however, in accord with regard to the unsatisfactory or fallacious nature of the open flashing test as laid down in the existing Petroleum Act.

The important objection raised against the open test is, that it is liable to "manipulation", i. e., that in consequence of certain very readily variable elements in the details of the test (added to the interfering action of even slight currents of air) the flashing point of one and the same sample of oil may be made to differ many degrees in the hands of different operators (or of one and the same operator at different times).

The majority of witnesses also were agreed in the opinion that the proposed "close test" was decidedly more reliable in itself and much less open to manipulation than the open test. The differences of opinion with regard to it were almost entirely confined to the necessity for some modifications in its details and to the relation which the results furnished by it bear to those obtained with the open test, or, in other words, the particular temperature which in dealing with the "close test" should be held to correspond to the standard or "flashing point" (100° Fahrenheit), fixed in the existing act as applied to the open test prescribed. On the latter point a very considerable difference of opinion existed between two sections of witnesses; on the one hand, the results of a number of experiments made by several witnesses with the close and open tests were adduced in support of the conclusion that a flashing point of 85° given by the close test should be accepted as equivalent to 100° by the open test, while on the other hand similarly strong testimony and extensive experiment supported the view that the standard flashing point for the close test (equivalent to 100°) should not be higher than 75°.

These differences of opinion were obviously ascribable, in great measure, to the unreliableness of the present (open) test, and also to certain variable points in the details of the "close test", which tend to allow of the results furnished by this test being also regulated (though not nearly to the same extent as with the open test) by small variations in the *modus operandi* adopted by different experimenters.

The opinion which I myself had formed from the results of practical experience in the employment of the flashing test, as prescribed in the schedule of the existing act, was quite in accordance with the general opinion of the witnesses examined before the House of Lords committee as to its untrustworthiness. Moreover, after careful consideration of the subject, it appeared to me, to say the least, very doubtful whether certain sources of error could by any modification of the arrangements and directions laid down in the schedule of the existing act be eliminated to such an extent as greatly to reduce the liability of the test to furnish results not fairly comparative with each other, and its susceptibility to "manipulation" or regulation in the hands of different experimenters.

Before proceeding to examine into the merits and defects of the proposed "close test", and to endeavor to supply the want of a generally satisfactory test (either by a modification of one of the known tests or by elaboration of some new method of experimenting), I considered it desirable to ascertain whether the additional experience of the last three years had led some of the principal witnesses and others who had given attention to this subject to modify the views expressed at that time or to form any decided opinion as to the direction in which a satisfactory solution of the difficulties connected with the present system of testing might be sought.

I therefore addressed circular letters (Appendix I) to the following:

Mr. T. W. Keates, consulting chemist of the Metropolitan Board of Works.

The late Dr. H. Letheby.

Dr. J. Attfield.

Mr. Dugald Campbell.

Dr. B. H. Paul.

The secretary of the Petroleum Association.

The secretary of the Scottish Mineral Oil Association.

The local authorities under the act at Liverpool and Bristol.

As the replies to my communications, which I received from several of the above, embody the present views entertained with regard to the test prescribed by the existing act and the points which require consideration in the attempt to provide a satisfactory test, I consider it advisable to give the following précis of such replies.

Mr. Keates says: "The present test fails by the nature of the test itself; it is not possible to preclude sources of inaccuracy in its use." He proceeds to point out that a considerable difference in results may arise with different operators, working with the utmost honesty of purpose according to the interpretation put upon the directions of the schedule of the act (as to rate of heating, application of test flame, etc.), but that "such differences are trifling as compared with those which can be obtained when there is a desire to get away from the truth", such differences being always in one direction, viz, in postponing the time at which the ignition of the vapor takes place. He proceeds: "I think it is conceded that the present open test is fallacious, and that it can be made to give different results by different operators, according to the wish or intention of such operator." Mr. Keates then dwells upon the merits of the close test, the adaptation of which he had advocated in 1872, and says: "With a proper regulation as to the application of the light to the vapor chamber very close agreement can be obtained, and I do not think the test is capable of manipulation." He expresses his belief that the close test is not objected to *per se*, but that the point upon which great difference of opinion exists is the difference to be made in the parliamentary standard of temperature if the close test be substituted for the open test, which was the main point of dispute in 1872.

The late Dr. Letheby stated that the difficulties in the way of obtaining trustworthy results with the present (open) test, applied "according to the spirit" of the instructions laid down, are manifold, arising in some cases from the faulty construction of the apparatus, in others from the erroneous method of working, and in others from the indefinite nature of the instructions." After discussing the difficulties included under these three heads, and pointing out that the instructions originally laid down by him, Dr. Attfield and myself, in 1869, embody most of the improvements and alterations required to make the present test more certain and satisfactory. Dr. Letheby proceeds to say that, "considering an open test must, under any circumstances, be uncertain, because of the diffusion of the petroleum vapor into the atmosphere," he thinks "a closed test would be more satisfactory", and that the only difficulty is the point at which the legal standard of temperature should be fixed. As regards this standard, he differs considerably from Mr. Keates, and in support of his view refers to experiments made by himself and Mr. Dugald Campbell (and confirmed by Mr. Norman Tate and Dr. Robinson), which were quoted in the evidence given before the House of Lords committee.

Dr. Attfield simply expresses the opinion that nothing short of an original investigation will lead to a satisfactory solution of the difficulties connected with the test.

Mr. Dugald Campbell discusses in detail the defects in the instructions laid down for the use of the present test, and which he regards as giving rise to the discrepancies occurring in the application of the test. He considers, from the results of his own experience, that if certain points, which he details in connection with the application of the open test, be adhered to, "independent experimenters would not *materially* differ in their results." Mr. Campbell's experience with the close test does not lead him to form so favorable an opinion of it as is entertained by Mr. Keates, but he considers that "with strictly defined rules for applying the test", which are carefully carried out, the results furnished by it "are likely, on the whole, to be rather more uniform than with the open test". He considers that some modifications in the construction of and mode of working with the close test as described in 1872 are necessary, and is in accordance with Dr. Letheby regarding the standard temperature which should be adopted with the close test (as equivalent to 100° with the open test).

Mr. B. Redwood, the secretary of the committee of the Petroleum Association, in expressing the views of that committee, considers that the difficulties which have arisen in the application of the present test are due to a "want of detail in the parliamentary directions for applying the test, and to the delicacy of the test or liability to uncertainty in the hands of unskillful operators". The committee consider that if directions with regard to the rate and uniformity of heating the apparatus, and of the size and character of the flame used for testing, had been strictly laid down, "the results of different operators would have *approximated* more closely, and that with *skilled persons* the results would have been *sufficiently uniform* to have given satisfaction. Inasmuch, however, as the inspectors under the act are men whose training has not qualified them to perform operations involving close details of manipulation, the committee are driven to the conclusion that the present test, even with such amended instructions for its use as have been instanced, would be found too delicate."

In discussing the directions which should be taken for providing a better test, stress is laid upon the desirability of adopting a system of testing which would preserve the existing standard of 100°, as the public, having been "educated in the belief that anything over 100° Fahrenheit means safety and below 100° danger, might associate any lowering of the standard with increased risk to themselves even if such lower standard were explained to be equivalent to an equally stringent and more certain test".

Mr. Redwood proceeds to consider the directions in which, failing the possibility of an efficient modification of the existing open test, another test might possibly be sought, and considers, with reference to these, that—

(*a*) The American or fire test (which consists in determining the temperature at which the surface of the heated petroleum takes fire permanently) is as open to discrepancies as the present legal test.

(*b*) The automatic tests which have been proposed (depending for their action upon the vapor traveling to a fixed distance and there becoming ignited) are too complicated for general use, and have not given encouraging results.

(*c*) The close test involves a lowering of the standard flashing point, and is therefore objectionable.

The committee of the Petroleum Association state their opinion through Mr. Redwood, that if it should not be possible to modify the open test so as, while preserving the present standard, to reduce its delicacy sufficiently to allow of its satisfactory employment "by an inspector of average intelligence", "the closed test would appear to be the best substitute, but would, of course, necessitate a reduction of the standard," in consequence of which "the prejudice created in the mind of the public would have to be combated". In the event of my deciding in favor of the close test, the committee refer me to Mr. Redwood's evidence before the House of Lords committee in 1872, in which he agrees with Dr. Letheby and Mr. Dugald Campbell regarding the standard temperature to be adopted in connection with this test as equivalent to the present legal standard of 100°.

In conclusion, the committee request that Mr. Redwood may be allowed to exhibit to me the precise method adopted by the Petroleum Association in testing the petroleum imported into London.

The Liverpool Petroleum Association expresses their concurrence in the statements submitted by Mr. B. Redwood, as secretary of the Petroleum Association.

The Local Government Board of Bristol adopt the views expressed by the representative of the petroleum trade in Bristol, Mr. F. F. Fox, to whom they referred my letter of inquiry, and who suggests that, "following the example" of the Petroleum Association of London, the object aimed at should be "such an improvement of the existing test as shall take away (if possible) its present imperfections, or, failing this, the adoption of the closed vessel, provided an equivalent standard be fixed".

The secretary of the Scottish Mineral Oil Association is desired to state that the directions, as detailed in the existing act, are much too indefinite, and that the test is subject to extraneous influences which produce discrepancies in the results of even conscientious and careful chemists. The association considers it desirable to have a testing apparatus, the range of variations of which cannot, under any circumstances, be more than two or three degrees, and that the close test is the most satisfactory and reliable one that can be adopted. Such an apparatus as was described in the proposed bill of 1872 is believed to meet the views of every one, and is certainly the most accurate test which has had the attention of the association. It should, however, be distinctly stated, with reference to this close-test apparatus, "that the movable cover for the circular opening should be removed only when the light is being applied, and immediately replaced if no flash be produced."

From the foregoing précis will be seen—

(1.) That the authorities quoted are agreed in regard to the unsatisfactory nature of the existing method of testing petroleum, as prescribed in Schedule 1 of the Petroleum Act, 1871.

(2.) That they are also in accord as to the great difficulty, if not impossibility, of modifying the existing "open test" so as to render it capable of uniformly insuring reliable and satisfactory results in the hands of different operators.

(3.) That the close-vessel test, which it was proposed to prescribe in the contemplated act of 1872, is more satisfactory than the present open test; but—

(4.) That differences of opinion exist with regard to the relation which the results furnished by this "close test" bear to the present open test; and—

(5.) That there are evidently some points of uncertainty connected with the proposed "close test" which render it also liable to furnish different results in the hands of different operators.

The results of my own experience with the present legal test, and a careful examination into the various points raised in the foregoing with regard to it, and to the "close test" which it has been proposed to adopt as a more trustworthy test, led me to the following conclusions:

(a) That the method of testing petroleum prescribed in Schedule 1 of the Petroleum Act, 1871 (34 and 35 Vict., cap. 105), is not of such a nature as "uniformly to insure reliable and satisfactory results".

(b) That the "close test", which it was proposed in 1872 to substitute for the existing "open test", and which was discussed in the evidence taken before a select committee of the House of Lords in session in 1872, though more satisfactory, is open to objection on several grounds, and is liable to furnish different results in the hands of different operators.

II.

With reference to the alterations in method of testing petroleum which should be adopted to secure reliable and satisfactory results.

In addressing myself to the preparation of a reply to the second point submitted for my consideration in the letter addressed to me by the Under Secretary of State for the Home Department, I proceeded, in the first instance, to consider whether it was possible to devise some method of testing differing entirely from either of those which have been referred to, and which would be likely to prove satisfactory, as being sufficiently simple, certain, and free from liability to involuntary or intentional modification in the hands of different operators. My examination into the merits of some automatic tests which have been proposed, and a trial of one or two other plans which suggested themselves, for comparing the volatility of samples of petroleum by operations placed more or less beyond power of control by the manipulator were not attended by promising results.

The possibility of modifying the present legal test (the open test), so as to reduce within satisfactory limits the existing sources of discrepancy, next received a most careful consideration by me; but I came to the conclusion that, supposing directions could be laid down or arrangements contrived for securing uniformity in the rate of heating the oil to be tested, in the temperature at which the operation of testing is commenced, and in the nature and mode of applying the test flame, one great source of uncertainty inherent in the test—namely, the free exposure to the air of the surface of the oil from which the vapor is evolved—would still remain.

At the suggestion of Mr. Boverton Redwood I witnessed some testing operations conducted with the open test, but with the employment, in place of the ordinary thermometer, of an ingenious combination of a thermometer and clockwork, devised by Mr. R. P. Wilson (a) (and called by him a chrono-thermometer), the stem of the thermometer being made, with its scale, to form a circular frame, surrounding a dial with clockwork. The object attained by this arrangement is to ascertain readily that the rate of heating is in accordance with any prescribed regulation, the hands of the clock being made to keep time with the rise of the thermometer. The same result is, of course, attainable in ordinary practice by having a timepiece in close proximity to the test apparatus, so that it may be watched at the same time as the thermometer and the rate of rise of the latter regulated accordingly. The employment of Mr. Wilson's arrangement is certainly more convenient than having to watch the thermometer and timepiece separately; but it adds a somewhat expensive item to the apparatus, and, supposing that by its employment uniformity in the rate of heating could be secured, only one element of uncertainty in the existing test would then be avoided.

The general concurrence in the comparatively satisfactory nature of the "close test" led me to consider next whether it might not be possible to remove the points of uncertainty involved in the employment of that test by different operators. The chief variable points connected with it are—

(1.) The rate of heating of the apparatus.

(2.) The nature of the test flame to be used.

(3.) The precise position in which the test flame is to be applied, and the duration and frequency of its application.

Considerable differences of opinion were expressed by experts in their examination before the House of Lords committee as to the rate of heating which should be adopted in the application of the open test, differences of opinion which apply equally to the "close test".

Having carefully considered this point, I have come to the conclusion that it is unimportant whether the rate of heating be 1° or 2° per minute or 20° in fifteen minutes (the three rates insisted upon by different witnesses in the evidence), or whether a decidedly different rate of heating be adopted, provided the source of heat and amount of heat employed, and the mode of applying it, be the same in all cases, such definite rules being laid down with respect to this, and such precautions being taken in the construction of the apparatus, as to render the attainment of uniformity by different operators simple and certain.

The suggestion to apply hot water as the source of heat in connection with a flashing test was made by one of the House of Lords committee in 1872, and Mr. Keates stated that this subject had received consideration, but that decided objections had been advanced against this mode of heating. Being strongly of opinion that hot water presented the only simple means of securing uniformity in the

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rate of heating, I made many experiments, with a view of attaining, by simple arrangements, a satisfactory rate of heating by its means, which should be uniform with different apparatus of uniform construction and dimensions. By inclosing the hot-water vessel in an air chamber (or a jacket with intervening air-space), and by interposing an air-space between the hot water and the receptacle for the petroleum, I succeeded, on the one hand, in satisfactorily retarding loss of heat by radiation, and, on the other hand, in securing a sufficiently gradual transmission of heat to the petroleum. The rate of transmission of heat is not uniform throughout all periods of one single operation, but it is uniform at the same periods in different operations, and the average rate of heating is uniform. At the commencement, when the petroleum is cold and the water at its maximum heat, the rate of heating is necessarily most rapid, while as the temperature approaches the flashing point the rise of temperature, which for some time previously has been very uniform, becomes somewhat slower. The comparatively rapid heating at the commencement of the operation is decidedly advantageous, and the diminution toward the close is not sufficiently great to increase the legitimate severity of the test.

The temperature of 130° Fahrenheit has been fixed upon as a convenient one for the water to have at the commencement of the experiment; this temperature gives, with the apparatus of the dimensions adopted, a *mean* rate of heating of about 2° per minute during an experiment. The only operation which is to be performed in preparing for the heating of the petroleum to be tested is, at starting, to fill the heating vessel entirely with water at 130° Fahrenheit. The supply of water of the required temperature may be prepared by adding hot to cold water, or the reverse, in a jug, and watching the thermometer, which is moved about in the water until the desired temperature is indicated. When the heating vessel is filled with the properly warmed water, the petroleum cup being immediately afterward placed in position, the operator has not to concern himself any further with regard to the heating, and has only to attend to the rise of temperature in the cup and to the test flame. When the next test has to be performed, the water in the bath may be again raised to the proper temperature by the application of a spirit-lamp flame, and this is readily accomplished while the test vessel is being emptied and refilled with a fresh sample of the petroleum to be tested.

That the rate of heating must be rendered uniform by this mode of operation when the temperature of different samples of petroleum to be tested does not differ greatly is self-evident, and experiment has shown that, even if considerable differences exist between the temperatures of different specimens, the extra time required to raise the colder oil to the temperature approaching that of the minimum flashing point does not seriously affect the uniformity of the rate of heating at that part of the operation when this uniformity is of importance. There is, however, no difficulty whatever in avoiding any great variations in the temperatures of the samples tested at different times; thus, the warmth of the hand will soon raise a cold oil to a normal temperature, and a warm oil is easily cooled down to such a temperature by immersing the bottle containing it in water. As long as the temperature of the samples at the time of testing ranges between 55° and 65° the uniformity in their rate of heating will not be affected to an extent to influence the results furnished by the test. As illustrating the uniformity in the rate of heating, it may be stated that in two experiments made with one and the same oil, the temperature of which at the time of starting the test was 64° in one experiment and 70.5° in another, the average rate of heating during the rise of temperature from 75° to 85° was almost identical, being, during that portion of the test, 1.04° per minute. The only difference in regard to the heating in the two experiments was that with the oil at the lower temperature a period of six minutes was required to raise the temperature to 75°, while with the warmer oil only four minutes were required to attain the same result. The illustrations of results furnished by the proposed test apparatus given at page 224 show conclusively that they are not affected by differences even greater than the above in the temperatures of the oils at the commencement of the test.

The nature of the test flame to be used, and the mode of using it, were next considered by me, and very much time and labor have been expended upon the endeavor to provide a test flame which, with little care, could be maintained for some time of uniform size, and which might be allowed to remain throughout the testing operation or during the greater part of the time in a fixed position over the vapor chamber of the petroleum cup, my desire being, if possible, to render the actual operation of testing perfectly automatic.

Having satisfied myself that with the petroleum cup filled to a definite height there is no objection to keeping a small aperture in the lid of the cup (similar to that which exists in the lid of the close-test apparatus) constantly open, a very small oil-lamp was contrived, capable of maintaining a flame of the size of the test flames (furnished by a small gas jet or by twine) used in connection with the present test, and the lamp was so attached to the apparatus that when the testing was proceeded with the position occupied by the test flame over the opening in the cup was inevitably the same in all instances.

The variations in the length of time for which the flame was applied, in the rapidity of its movement in and out of the opening and in the frequency of its application, all constituted sources of discrepancy between the results obtained by different operators with the two tests hitherto used, which I proposed to set aside in the manner above indicated, i. e., by keeping the small lamp in a fixed position from the time when the rise of temperature indicated an approach to the lowest attainable flashing point until the completion of the operation. This result was attained after numerous modifications of the small test lamp, and the form of the latter which I eventually adopted permitted of the attainment of uniformity in the size of the test flame by a very simple trimming operation.

The position in which the thermometer was fixed into the lid of the petroleum cup was modified so as to allow of the reading of the temperature simultaneously with the watching of the test flame being much more conveniently performed than in the present apparatus.

Although very satisfactory results were obtained by the arrangements just referred to, some difficulties were experienced in keeping the flame of the test lamp of uniform size throughout a consecutive series of test operations, and slight currents of air were found to affect the results obtained too greatly to render the test thoroughly reliable. After a long series of experiments, carried out with the view of overcoming these difficulties, I was eventually led to return to a method of operation very similar to that adopted in the original " close test", but with this important difference, that uniformity was secured in the nature of the test flame, the mode of applying it, and the position in which it is applied.

The application of the flame is in fact rendered quite automatic in the proposed form of test apparatus, the mode of operation being as follows :

The top of the petroleum cup has an aperture, as in the case of the old close-test apparatus, but in the center of the lid; this aperture is kept closed by means of a metal slide, working in grooves, and having two small uprights. These uprights support the little test lamp, which for this purpose is fitted at the upper part with small trunnions. When the temperature of the petroleum approaches that of the minimum flashing point, the slide is slowly drawn out of the grooves to the full extent permitted by a check; when this point is just reached, a very simple contrivance causes the test lamp to be tilted, so that the flame is always lowered into the opening in exactly the same position. Two seconds of time are allowed for withdrawing the slide, and thus the test flame is applied in all instances for the same period. (a) This operation is repeated at the termination of every degree indicated by the thermometer until the flashing point is attained.

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a A small weight, suspended in front of the operator from a string 2 feet in length, answers the purpose of regulating the opening and shutting of the aperture. The slide is gradually drawn open during three oscillations of the pendulum, and is then rapidly closed during the fourth.

In this, as in the old close-test apparatus, each time the aperture is reopened and the test flame is applied a small portion of the mixture of air and petroleum vapor necessarily escapes from the chamber, in consequence of the outward current established, and hence the proportion of air in the mixture of vapor and air formed in the chamber must become reduced each time the test is applied, and thus the ready explosiveness of the mixture is liable to some variation. A simple contrivance has been applied in conjunction with what may be called the "testing slide" for remedying this possible source of discrepancy in the test. The opening which the withdrawal of the slide exposes for the application of the test flame is in the center of the upper surface of the chamber. Just before it becomes open to the full extent, and the test flame is lowered into place, two smaller openings, one on either side of it, become also uncovered by the drawing back of the slide and serve to admit air to replace that part of the mixture of air and vapor which is withdrawn from the chamber by the current which sets in the direction of the test flame; as the slide is pushed back again, these two openings are closed the instant before the central opening is closed again.

The description of oil and wick most suitable for the little test lamp are given in Appendix II. When coal-gas is available, it may be substituted for oil in the production of the test flame, as being decidedly more convenient, and for this purpose an arrangement which can be used in place of the lamp, and which admits of a small gas frame being applied automatically in exactly the same manner as the oil flame, has been devised as an alternative adjunct to the apparatus.

Even with a strict adherence to the prescribed method of heating the petroleum to be tested, and with the employment of the automatic test arrangement constructed precisely in accordance with the instructions laid down in the appendix, uniform results would not be obtained in the application of the test unless the petroleum cup be filled in all instances up to to the same height, and, indeed, up to a height which a long series of experiments (varied in many ways) has demonstrated to be the one which best insures the attainment of uniform results. A simple gauge, consisting of a small bracket, terminating in a point, is fixed within the cup, and indicates the precise height up to which this is to be filled with the liquid, which has simply to be poured in gradually until its level just reaches the point of the gauge.

The thermometer which serves to indicate the flashing point is rigidly fixed into the lid of the petroleum cup in a sloping position, so that it enters the liquid at the center of the surface. The length of that part of the thermometer which is inclosed in the cup is so adjusted that when the latter is filled to the prescribed height the surface of the liquid is 0.2 inch above the bulb. The precautions combine to render the readings obtained with the thermometer reliable indications of the actual temperature of the petroleum during the testing operation. The sloping position of the thermometer scale enables readings to be very conveniently taken.

Detailed instructions with regard to the application of the proposed method for testing are given in Appendix II, and Appendix IV gives the details of the proposed test apparatus.

The method of testing, arranged as described, is so simple in its nature that any person of ordinary intelligence, after carefully reading the instructions, or after having been once shown the operation, can carry it out readily, and no experience is required for the attainment of uniform results with it.

The following results, not selected, which have been obtained with the pattern apparatus sent with this report, illustrate the uniformity in the working of the test as now elaborated, and it should be particularly noted with respect to these results that in experiments with one and the same sample considerable variations in the temperature of the oil at the commencement of the experiment did not affect the accuracy of the results obtained:

Sample.	No. of experiment.	Temperature of bath at commencement.	Temperature of oil when placed in bath.	Temperature at which testing was commenced.	Flashing point.	Sample.	No. of experiment.	Temperature of bath at commencement.	Temperature of oil when placed in bath.	Temperature at which testing was commenced.	Flashing point.
		Deg. F.	Deg. F.	Deg. F.	Deg. F.			Deg. F.	Deg. F.	Deg. F.	Deg. F.
A.	1	130	66.0	68	77	K.	2	130	63.0	71	82
	2	130	68.5	70	77		3	130	66.0	69	82
	3	130	69.5	71	77	L.	1	130	54.0	68	75
B.	1	130	70.6	71	80		2	130	53.5	64	75
	2	130	71.0	71	80	M.	1	130	54.0	66	81
C.	1	130	68.0	70	82		2	130	67.0	69	81
	2	130	69.0	70	82	N.	1	130	57.0	63	73
	3	130	70.5	71	81		2	130	59.0	60	72
D.	1	130	59.0	63	75		3	130	57.0	63	73
	2	130	63.5	67	76	O.	1	130	62.0	67	79
	3	130	70.0	71	76		2	130	57.0	63	79
E.	1	130	57.0	65	72	P.	1	130	60.0	65	79
	2	130	59.0	62	71	Q.	1	130	59.0	65	74
	3	130	61.0	62	72		2	130	57.0	67	75
	4	130	63.5	69	72		3	130	67.0	67	75
F.	1	130	63.0	65	78	R.	1	130	66.0	69	78
	2	130	65.0	70	78		2	130	64.0	67	78
	3	130	66.6	67	78	S.	1	130	64.0	65	70
G.	1	130	70.0	70	84		2	130	63.0	64	70
	2	130	74.8	75	84	T.	1	130	63.0	66	80
H.	1	130	74.0	75	80		2	130	64.0	75	79
	2	130	65.0	66	80		3	130	65.5	75	80
I.	1	130	68.0	68	78	U.	1	130	66.0	67	73
	2	130	65.0	67	78		2	130	64.0	69	74
J.	1	130	59.0	68	79		3	130	67.0	68	74
	2	130	58.0	60	79	V.	1	130	67.0	69	80
K.	1	130	57.0	61	81		2	130	70.0	70	80

It will be seen that the foregoing table embraces a considerable range of flashing points; the samples which gave the results there recorded had flashing points ranging from 98° to 126°, as determined by the present legal test. All these were examined with equal facility and with equal accuracy (as shown by the results obtained with one and the same sample), the temperature of the water in the heating vessel having been in all instances 130° at starting. But with oils of much higher flashing points than the highest in the above

series the supply of heat furnished by the amount of water contained in the heating vessel, raised to a temperature of 130°, would not be sufficient; and even if in such cases the water in the bath be raised to a much higher temperature, the intervention of the air space between the petroleum cup and the source of heat (which plays an important part in regulating the source of heat in the ordinary use of the test) prevents the very high flashing oil from being raised to its flashing point within any reasonable period. If, therefore, the first experiment made in the ordinary prescribed manner with a sample of oil indicates a very high flashing point (about 100° or upward), the following modified mode of proceeding must be adopted for determining its flashing point. The air chamber which surrounds the cup is filled with cold water to a depth of 1¼ inches, and the heating vessel or water-bath is filled as usual, but also with cold water. The lamp is then placed under the apparatus and kept there during the entire operation. (a)

With this simple modification of the ordinary mode of working concordant results will be obtained with oils of the highest flashing points. It need hardly be stated that the greater majority of petroleum oils have flashing points within a smaller range than that represented by the annexed tabulated results, and that the application of the mode of proceeding last described will be limited to comparatively heavy paraffine oils, of which it is desired to determine the flashing points.

Having satisfied myself of the satisfactory working of the proposed test apparatus, I invited Mr. Keates, the consulting chemist to the Metropolitan Board of Works, and Mr. B. Redwood, the secretary of the Petroleum Association, to inspect it, and to witness the operation of testing with it. The appended extracts of letters (Appendix III) from those gentlemen show that they concur in considering that the difficulties which existed in connection with the present legal test, and also, though to a less extent, with the close test in the form in which it was proposed by Mr. Keates, are removed by the mode of operating which has been elaborated.

At the instance of Mr. Peter McLagan, M. P., the apparatus was also inspected by a representative of the Scottish Mineral Oil Association, Mr. John Calderwood, whose unqualified approval of it is recorded in the appended extract of a letter from him (Appendix III).

III.

With reference to the "flashing point", which, with the proposed test, should be fixed as equivalent to that of 100° Fahrenheit obtained with the present legal (open) test, and to the question whether the flashing point of 100°, or its equivalent, is "calculated to afford efficient protection to the public without unduly interfering with or restricting the trade".

With the view to establish the relation existing between the results furnished by the proposed test and by the present legal test experiments were made with a series of samples of petroleum, the flashing points of which had been determined by the test as prescribed in the act. Among these samples there was a considerable number for which I am indebted to the kindness of the secretary of the Petroleum Association.

As Mr. Boverton Redwood has had great experience in the testing of petroleum, both by the open test and by the close test, which it was at one time proposed to adopt, I requested him to attend at my office and test a number of the samples with which he was so good as to provide me.

In the first instance, however, I convinced myself that the results which that gentleman obtained by operating according to the directions laid down in the act, and also by applying the original close test, agreed very well with those obtained by Mr. T. W. Keates and by an experienced assistant in my establishment. Mr. Redwood and Mr. Keates were so good as to attend at my department to exhibit to me their ordinary mode of operating in applying the test, and the flashing points ascribed by those gentlemen (operating on different days) to particular samples were sufficiently in accordance to warrant my accepting the numbers obtained by Mr. Redwood in testing the series of samples referred to as representing the flashing points which would generally be obtained by experienced persons operating according to the methods hitherto practiced.

There is no doubt that the flashing points which one and the same operator, of such experience as Mr. Keates and Mr. Redwood, obtains with different samples of oil, using one and the same open test or close test apparatus, bear very generally a correct relation to each other; occasions will, however, unavoidably arise, even under the above very favorable conditions, when the defects inherent in those methods of testing will give rise to irregular and discordant results. Hence it is not to be expected that flashing points furnished by the comparatively accurate method of testing now proposed should present anything approaching absolute uniformity of relation to all those furnished by either of the other tests. Thus, as might have been anticipated, among the samples of oil which have been tested with the new apparatus there are several which, though they gave flashing points identical or nearly so with each other when examined by the present legal test (the open test), were found to differ several degrees from each other as regards their flashing points when examined by means of the new test.

In the examination of a number of samples by the new test and by the proposed close test the relation between the flashing points furnished by the two tests varied somewhat; the "new test" flashing points ranging from two to five degrees lower than the results furnished by the close test. Of 26 samples, ten gave flashing points with the new test 4° lower than the results obtained with the old close test, six gave results 5° lower, five 3° lower, and five 2° lower.

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a With oils of very high flashing points the rate of heating does not affect the accuracy of the results obtained. Therefore, if it is known to the operator that he is dealing with oils of very low volatility, he may save time by starting with the water raised to a temperature of about 120°. The following results are given in illustration of this:

Description of samples.	No. of experiment.	Temperature of bath at commencement.	Temperature of oil when placed in bath.	Flashing point.
		Deg. F.	Deg. F.	Deg. F.
I.	1	78	78.0	147
Young's patent lubricating oil	2	110	74.0	146
	3	120	80.0	147
II.	1	74	74.0	131
Young's patent lubricating oil	2	100	68.0	130
	3	100	72.5	131
	4	111	72.0	131

In applying the new test to 29 samples which had been examined by the present legal (open) test the following results were obtained:

Number of sample.	Flashing points by open test.	Flashing points by new test.	Difference.
	Deg. F.	Deg. F.	Deg. F.
1	98	70	28
2	100	71	29
3	100	72	28
4	100	74	26
5	100	75	25
6	101	73	28
7	101	78	23
8	101	74	27
9	102	75	27
10	103	75	28
11	104	75	29
12	104	76	28
13	104	77	27
14	104	78	26
15	104	78	26
16	105	80	25
17	106	79	27
18	106	80	26
19	106	81	25
20	108	82	26
21	108	83	25
22	108	80	28
23	109	84	25
24	110	83	27
25	110	82	28
26	110	81	29
27	110	81	29
28	113	87	26
29	126	100	26

t will be seen from an examination of these numbers that one among the samples gave a flashing point with the new test only 23° lower than that given by it when examined by the open test, while with four others there was as great a difference as 29° between the flashing points furnished by the new test and the present legal test. Excluding the single sample which showed the comparatively small difference above specified between the two tests the following is a synopsis of the observed differences between the two tests:

Number of samples.	Differences between the flashing points furnished by the two tests.
	Deg. F.
5	25
7	26
5	27
7	28
4	29

It would appear, therefore, from the results of these experiments, that the difference between the flashing points furnished by the present legal test and those obtained with the proposed new test ranges from 25° to 29° inclusive, and it should be borne in mind that the "new test" flashing points which have indicated this range of differences are all the results of two or three concordant experiments.

Taking samples of oil which by the "open test" gave flashing points of 100° and 101° (of which there are seven in the above series), the flashing points of these samples, determined by the "new test", ranged from 71° to 78° inclusive. Again, the flashing points of five samples, which were all shown to be 104° by the open test, ranged with the new test from 75° to 78° inclusive. Three samples, having all a flashing point of 106°, as determined by the open test, gave flashing points ranging from 80° to 82° inclusive by the new test; three, all flashing at 108° (open test), ranged from 80° to 83°, and four, flashing at 110° (open test), ranged from 81° to 83° inclusive. Oils of flashing points between 98° and 106° inclusive (open test) gave flashing points ranging between 70° and 80° by the new test, and those which with the open test ranged from 106° to 110° inclusive gave results with the new test ranging from 80° to 84° inclusive.

While the open test (the present legal test), and even the close test which has been proposed as its substitute, give what may be termed broad results, the new test, which appears to be as nearly absolute as a test of this kind can be made, gives precise results. For this reason, I am of opinion, so far as the results which have hitherto been obtained with the new test warrant my speaking decisively on the subject, that it will be necessary with the new test to adopt a range of 4 or 5 degrees to correspond to what has hitherto been regarded as the minimum flashing point which petroleum oils supplied to the public should have; in other words, I consider that the difference between the results furnished by the new test and the present legal test cannot be expressed by one figure, but must be represented by a range of figures (say, from 25° to 29°).

It need hardly be pointed out that great difficulties have arisen in connection with the present regulations respecting the testing of petroleum oils, consequent upon the legalized acceptance of oils as safe, or their condemnation as dangerous, upon a difference of even one degree in their flashing points, as determined by a test which may give differences of several degrees with one and the same oil in the hands of different operators.

With the adoption of a comparatively precise test, such as there is good reason for believing the proposed one to be, these difficulties should cease to exist, and I consider that a minimum flashing point may be adopted and strictly enforced with the employment of the new test without creating an opening for justifiable differences of opinion, such as have arisen in connection with the present legal test.

Having given my earnest attention to the evidence brought before the House of Lords committee in 1872, and to the questions which have arisen from time to time respecting the occurrence and causes of explosions or other accidents with petroleum, I have come to the following conclusions:

(1.) The present legal "flashing point" of 100° Fahrenheit by no means limits the acceptance of oils of that supposed flashing point to such as have only one particular degree of volatility, but indeed may admit oils as being just within the prescribed limits which really differ decidedly from each other as regards volatility.

(2.) There appear, on the other hand, to be no well-established grounds for considering that "adequate protection to the public" has not been afforded by adopting the flashing point of 100° Fahrenheit as the limit with the present legal test, or that the general results which that test has furnished in its application to determine whether oils imported have flashing points below the prescribed limit have been productive of risk to the safety of the public, even though there may be reason to believe that occasionally oils submitted as just within the limit have had decidedly lower flashing points than those of other oils which have been recorded as identical with them in this respect.

It may therefore be considered that the minimum flashing point to be adopted in connection with the new test may, without danger to the public, be fixed at that point which corresponds to the lowest results (not exceptional) which are furnished by applying the new test to a series of oils having a common flashing point of 100° when examined by the present legal test.

It may also be considered that the fairest course would be to base the equivalent, with the new test for 100° (furnished by the open test), upon the mean of the differences between the two tests applied to a large number of oils (with possibly the exclusion of a completely exceptionally extreme result). The objection would probably be raised against this course by importers of petroleum oils that it would have the effect of excluding from the market some oils which, under the present act, might be admitted as having a flashing point of 100°, and which past experience has failed to prove dangerous. Thus, if the mean difference between the flashing points given by the two tests in the results shown in the foregoing table be accepted as determining the equivalent for the present legal minimum flashing point (100°), then that difference being 27°, the equivalent for 100° would, with the new test, be 73°; but if that be adopted as the minimum legal flashing point with the new test, two out of 28 samples which the present legal test might have admitted would have been excluded from the market if the new test were in force.

Looking to the fact that these two particular samples, though found to have a flashing point of 100°, gave lower results than others of the same flashing point, not only with the new test, but also with the close test, it does appear as if they were oils of just that class which has given rise to occasional disputes, namely, oils which in the hands of some operators would have had flashing points below 100° assigned to them, and which might, therefore, even under the present conditions of testing petroleum, be excluded from the market by the balance of conflicting opinions.

After carefully considering this question, I have come to the conclusion that 27° Fahrenheit might, without injustice to the trade, be accepted as the difference between the results to be furnished by the new test and the present legal test; or, in other words, that 73° might with the new test be accepted as the equivalent for the present legal minimum flashing point of 100°.

It appears to me, however, that it would be much more satisfactory if, before a final decision is arrived at on this point, a very considerably larger number of experimental data than those which I have been enabled to obtain with the means at my command were procured with the new apparatus and by several operators experienced in the employment of the old tests. It would unquestionably much facilitate and expedite further action in the matter of modification of the existing law with reference to the testing of petroleum, etc., if Mr. Keates, of the Metropolitan Board of Works, Mr. Redwood, of the Petroleum Association, and an experienced operator selected by the Scottish Mineral Oil Association were invited to obtain test apparatus made in exact accordance with the pattern apparatus now submitted and to apply it to the testing of a number of samples of petroleum, the flashing points of which had also been determined by the present legal test. If portions of those samples, with the results obtained, were then forwarded to me by those gentlemen, apparent discrepancies could be examined into, and the "equivalent flashing point" of the new test be established upon a large number of results to the satisfaction of all interested in the adoption of a uniform system of testing.

If this suggestion be acted upon, I would recommend that the same person who, under my direction, has constructed the pattern apparatus, should make the apparatus required by those gentlemen, and that those apparatus should, in the first instance, be compared by me with the pattern now submitted.

In the event of the adoption of the new test, the apparatus submitted with this report (and of which photographs, (a) measurements, and specification are appended) should be preserved as a standard apparatus and placed in charge of some competent and suitable authority (e. g., under the weights and measures office), who should inspect and test, or have tested, all apparatus which are made for use under act of parliament, for the purpose of ascertaining that they are in accordance with the pattern and specification. Such apparatus should then bear some official stamp or mark by which they can be identified as legal apparatus.

Since the attainment of uniform results with the test is dependent upon the uniform construction of the apparatus, it is indispensable that such a course should be pursued, and its adoption could, I apprehend, present no practical difficulties.

In conclusion, I submit, with special reference to the letter of the Secretary of State for the Home Department of July 7, 1875, 1386a 61, Appendix V, the following brief summary of the results and conclusions to which I have been led by the inquiry which forms the subject of this report:

(1.) The method of testing petroleum as prescribed in Schedule 1 of the Petroleum Act, 1871 (34 and 35 Vict., c. 105), is not "of a nature uniformly to insure reliable and satisfactory results".

(2.) A method of testing petroleum has been elaborated for adoption in place of that prescribed in the petroleum act, 1871, due regard having been had to the fact "that the testing must in many instances be carried out by persons who have had comparatively little experience in conducting delicate experiments". This method, while resembling in its general nature the one hitherto used, is free from the defects inherent in the latter, and is so arranged that it can be carried out, with the certainty of furnishing uniform and precise results, by persons possessing no special knowledge or skill in manipulation. With ordinary attention, in the first instance, to simple instructions, different operators cannot fail to obtain concordant results with it, and it is so nearly automatic in its nature that it is not, like the present method of testing, susceptible of manipulation so as to furnish different results at the will of the operator.

(3.) There are not, in my judgment, any well-established grounds for considering that the present flashing point of 100° Fahrenheit is not "calculated to afford adequate protection to the public".

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a These are necessarily omitted from this reprint.—B. R.

(4.) With the employment of the new test, a minimum flashing point should therefore be adopted which is equivalent, or as nearly as possible so, to the flashing point of 100° Fahrenheit, as furnished by the present test.

(5.) From the uncertain character of the present test, it follows that the "flashing points" furnished by it are not always concordant with oils of the same degree of volatility, and that the same flashing point is sometimes assigned by it to oils of different degrees of volatility. On the other hand, the comparatively very precise test now proposed furnishes, of necessity, concordant results with oils of the same degree of volatility. Hence the differences between the "flashing points" furnished by the present test and those obtained with the new test cannot be strictly represented by one figure, but may be considered as ranging from 25° to 29° Fahrenheit (inclusive).

(6.) The results of a number of thoroughly concordant experiments with the new test, and a comparison of these results with those furnished by the present legal test, and also with those obtained by employment of the close test, which it was proposed to adopt in 1872, indicate that a mean difference of 27° Fahrenheit may be legitimately accepted as the mean difference between the present test and new test, and that therefore a flashing point of 73°, furnished by the new test, may be accepted as equivalent to the minimum flashing point of 100° adopted in connection with the present test.

(7.) Although the conclusions given in the preceding paragraph are based upon the results of a number of carefully conducted and controlled experiments, it appears desirable that the minimum flashing point to be adopted in connection with the new test should be deduced from the results of a much larger number of experiments, and that these should be carried out with the proposed test apparatus by several independent operators of acknowledged experience in the testing of petroleum according to the methods hitherto practiced.

(8.) It is therefore proposed that several test apparatus, precisely similar in construction to that submitted with this report, be prepared, and that, after having been found by me to furnish identical results, they should be employed by the chemist of the Metropolitan Board of Works, the secretary of the Petroleum Association, and a duly qualified representative of the Scottish Mineral Oil Association for the testing of a number of samples of petroleum, the results, together with portions of the samples tested, being forwarded to me, with the view of their forming a basis for final report to the Secretary of State for the Home Department on that particular point.

(9.) In the event of the adoption of the test apparatus submitted with this report, it is important that the standard apparatus, with drawing and specification, should be deposited with some government authority, whose duty it would be to examine and certify to the correctness of all apparatus made for the purpose of testing petroleum under the new legalized regulations.

F. A. ABEL,

Augusr 12, 1876.   *Chemist of the War Department.*

Immediately upon receiving this report from Professor Abel, the Secretary of State for the Home Department requested Mr. Boverton Redwood to subject a large number of samples of oil to comparative tests, in order that the relation between the temperatures at which oils flashed when tested under the act of 1871 and when tested by the apparatus contrived by Professor Abel might be accurately determined.

The samples tested numbered 1,000. They represented (excluding the trial samples) 97,766 barrels of oil, and formed a series thoroughly indicating the character of the various shipments which have reached England from the United States during a period of six months. The following is a synopsis of the results, taking the first 968 samples, all of which consisted of the ordinary (refined) petroleum of commerce:

92 samples showed a difference between the two tests of	25°
208 samples showed a difference between the two tests of	26°
225 samples showed a difference between the two tests of	27°
281 samples showed a difference between the two tests of	28°
162 samples showed a difference between the two tests of	29°
968	

Therefore, the whole of these samples afforded results within the range of figures given in Professor Abel's report.

On the other hand, it will be noted that the majority of the last 32 samples gave differences smaller than the minimum figures of Professor Abel's results, the difference being as follows:

9 samples showed a difference between the two tests of	20°
1 sample showed a difference between the two tests of	21°
9 samples showed a difference between the two tests of	22°
1 sample showed a difference between the two tests of	23°
4 samples showed a difference between the two tests of	24°
8 samples showed a difference between the two tests of	25°
32	

These, however, all consisted not of ordinary petroleum oil, but of the special kind which is known in the trade under the name of "water-white" oil, and therefore the exceptional results afforded by them do not affect the question at issue, and are of interest only as showing that samples may be selected or specially prepared having flashing points by the two systems more closely approximating than those of the ordinary petroleum oil of commerce. This water-white oil, as is well understood, possesses the distinctive feature of low specific gravity in addition to that of high flashing point, being, in fact, produced at a considerably enhanced cost, by rejecting, in the process of distilling the crude oil, an unusually large proportion of the heavier as well as of the lighter hydrocarbons; and it is possible that this peculiarity may account for the smaller difference between the two tests, though I can suggest no explanation of its occurrence only with *some* parcels of water-white oil, unless it be that the special mode of manufacture referred to is more carefully carried out in some cases than in others. (a)

On the whole, the results which I have obtained afford a complete corroboration of those given in Professor Abel's report. The selection of a mean difference of 27°, or, in other words, of a standard of 73° with the new test, would undoubtedly, as is evidenced by my figures, lead to the condemnation by the committee of the Petroleum Association of a somewhat larger percentage of the oil imported, and would thus place the trade in a more unfavorable position; but, on the other hand, the adoption of a precise method of testing would reduce to a minimum those differences of opinion which, under the present system, may, as Professor Abel points out, lead in certain cases to the legal condemnation of oils which the trade inspection has shown not to come within the provisions of the petroleum act. (b)

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a These "water-white" oils were not cracked oils.—S. F. P.

b Report of Mr. Boverton Redwood to the English Secretary of State for the Home Department.

It is not my intention in this report to advocate the claims of either the Saybolt, the Abel, or the Engler apparatus for testing oils, which are doubtless superior to all the others, but simply to present the subject as it actually exists, with all the difficulties attending it, and also such attempts as have been made to meet them.

SECTION 4.—PETROLEUM LEGISLATION IN THE UNITED STATES.

In order to secure full information regarding legislation regulating the sale of petroleum products a schedule of questions was prepared and sent to the executive officer of each of the cities and towns having a population of 10,000 and upward, as represented in Census Bulletin No. 45. Some of these schedules were filled with very great care, others were carelessly filled, others were returned with an indorsement of "no legislation" or something equivalent, and in some cases no return was made. The same schedule was also addressed to the secretaries of the different states and the secretaries of the different state boards of health, from nearly all of whom returns were received. I was present in April, 1881, at a meeting of the committee of the New York legislature having in charge the legislation then pending relating to the sale of petroleum products, and was also frequently consulted by committees of the Minnesota legislature during the successive years in which the subject was agitated in that state.

From these several sources of information, of both a negative and a positive character, it appears that at the close of the census year seventeen out of the thirty-eight states of the Union were without other legislation relating to petroleum than that provided by the United States statute of 1867 (*a*) regarding mixing oils and prescribing a test of 110° (not given in the Revised Statutes), and an act regarding dangerous freight or stores on passenger steamers, (*b*) except that within those states there was a large number of cities having ordinances providing some test. Even the District of Columbia, whose laws are directly prescribed by Congress, has no other petroleum laws than the United States laws indicated above. Since the close of the census year a number of these seventeen states have passed laws relating to petroleum.

It was found to be impossible to compile any general statistics as to laws even from the schedules that were most carefully filled; but the returns exhibited the confused condition of legislation regarding petroleum enacted by so many different legislative bodies more or less influenced by a great variety of opinions and interests. On the one hand there are advocates of extremely high test laws who have made their influence dominant in certain localities, and that influence has produced legislation that has either been openly disregarded or strenuously opposed until the repeal of the obnoxious laws had weakened the cause they were intended to strengthen. On the other hand, while there are honorable manufacturers of petroleum who make and sell safe oils and desire to be relieved from competition with the manufacturers of unsafe products, there are others who, without regard for the welfare of the public, desire to be allowed to make what they can sell, leaving the question of responsibility with the purchaser, and who therefore oppose all legislation, using their influence to secure the lowest test possible when legislation is inevitable.

When the United States law of 1867 was passed the proportion of cracked oils in the market was much smaller than at present. That law required a fire test of 110° F. I have been unable to ascertain upon what basis the adoption of this test and the temperature rested. Several years subsequent to the enactment of this law the board of health of the city of New York made the whole question of dangerous petroleum products the subject of a most elaborate research by Dr. C. F. Chandler, and in consequence rejected the "fire test" as worthless and recommended to the city government the enactment of an ordinance that required a "flash test" as the only one of any value. The wisdom of this action has been indorsed by the whole course of English petroleum legislation. Some of the most able scientific men of this generation, after careful investigation of the subject, have shown that

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a And be it further enacted, That no person shall mix for sale naphtha and illuminating oils, or shall knowingly sell or keep for sale or offer for sale such mixtures, or shall sell or offer for sale oil made from petroleum for illuminating purposes inflammable at less temperature or fire test than one hundred and ten degrees Fahrenheit, and any person so doing shall be held to be guilty of a misdemeanor, and on conviction thereof, by indictment or presentment in any court of the United States having competent jurisdiction, shall be punished by a fine of not less than one hundred dollars, nor more than five hundred dollars, and by imprisonment of not less than six months nor more than three years. (U. S. Stat. at Large, Thirty-ninth Congress, second session, 1867, chap. 169, sec. 29.)

As this section is a part of an act relating to internal revenue, the other sections of which have no relation whatever to petroleum legislation, it is an open question if, in the repeated revisions to which the internal revenue laws have been subjected, section 29 has not been long ago repealed.—S. F. P.

b SEC. 4472. No loose hay, loose cotton, or loose hemp, camphene, nitro-glycerine, naphtha, benzine, benzole, coal-oil, crude or refined petroleum, or other like explosive burning fluids or like dangerous articles, shall be carried as freight or used as stores on any steamer carrying passengers. * * * Refined petroleum which will not ignite at a temperature less than one hundred and ten degrees of Fahrenheit thermometer may be carried on board such steamers upon routes where there is no other practical [practicable] mode of transporting it, and under such regulations as shall be prescribed by the board of supervising inspectors with the approval of the Secretary of the Treasury. * * *

SEC. 4474. The Secretary of the Treasury may grant permission to the owner of any steam vessel to use any invention or process for the utilization of petroleum or other mineral oils or substances in the production of motive power, and may make and enforce regulations concerning the application and use of the same for such purpose. * * *

Sec. 4475 prescribes the packing and marking of such oils, and Sec. 4476 prescribes the penalties for violation of the law. (Revised Statutes, U. S. Ed., 1878.)

a "fire test" is unsatisfactory, and also that a "flash test", at a temperature equivalent to that of 100° F. in an open tester, is a satisfactory test to insure public safety. Oils that will sustain a "fire test" of 110° often flash at 70° to 80°. While the overwhelming mass of evidence goes to show that a flash test of 100° is conclusive as regards public safety, there are large areas of the country with flash tests fluctuating between 120° and 150° as successive legislatures deal with the question, and other large areas where there is no state legislation. Under both these conditions the number of "kerosene accidents" is very large, while that portion of the country over which petroleum legislation is really effective is comparatively small.

The acts that have proved most effective in affording protection to the public have provided that a state inspector, authorized to appoint deputies, shall be chosen by the governor, county judges, or state board of health, who shall inspect oils by testing each for either its flashing or its burning point, or for both, at a specified temperature. Provision is usually made for the payment of the inspector and deputies. In some instances this compensation is made too low to compensate a competent person for doing the work properly. The instrument with which the test shall be made is in many cases carefully described. Then the bonds of the inspector and of the deputies are fixed, and the penalties for violation of the provisions of the law are prescribed.

There are two sources of danger against which legislation should be directed. The first is the *manufacture* of unsafe oils; the second is the preparation of unsafe oils by *mixture*. The machinery of state inspection is cumbersome as related to the manufacturers, and inoperative as regards the dishonest, who will mix safe oils with benzine. The expense of an analysis or inspection of every barrel of oil sold in this country in such a manner as to be of any value is unnecessary, as these oils are transported in tank cars that hold on an average 100 barrels. The inspection of the contents of a car is of just as much value as the inspection of each particular barrel. The idea that one part or stratum of a tank of oil will test differently from another has no foundation in fact. Having conversed with a large number of persons connected with the petroleum trade, I am convinced that legislation embodying the following provisions would reduce the number of petroleum accidents to a minimum, and would meet the approval of all honorable men. To determine, as a first step, what method of testing, what instrument, and what temperature should be adopted as a standard of legislation, the President might be authorized by Congress to appoint a commission, in which the boards of health, scientific experts, and manufacturers of petroleum should be represented equally. It would be well to ask the governments of foreign countries, with which the trade in petroleum is large, to join in the consideration of this question through special commissioners. A small percentage of the losses of the country during a single year would pay all of the expenses of this commission. Upon the report of such a commission, laws could be based making the selling of a dangerous oil a misdemeanor in all cases, and manslaughter when death is occasioned by its use, as already provided when death results from illegal transportation of "nitric oils" and powder, and also providing for the recovery of damages in a civil suit for all losses to either persons or property occasioned by the use of such oil —the retailer to be able to recover from the jobber, the jobber from the manufacturer, etc., until the responsible party is reached. One competent person, who should be authorized to enter premises and demand samples of oil for inspection, could do all of the necessary work for a large state, and he should be paid an adequate salary, not paid by fees. The examination of oils should not be confined to the flashing point alone, but should regard the percentage of sulphur, of benzine, and of heavy oil as well. This suggestion has met the approval of persons representing the producing, the manufacturing, and the selling interests as one which would make the manufacture of unsafe oils unprofitable, and, in addition, would prescribe penalties for the man who would willfully mix benzine with a good oil, tending to stamp out that nefarious business. In addition to a standard of testing for ordinary illuminating oils, another and much higher standard should be determined for oils to be used on steamboats and railroad cars in interstate commerce. Under present legislation, a car running over a thousand miles of road may start in a state in which a 110° oil is legal, and, passing through another in which a 300° oil is required, finish the run in a third state in which there has been no state legislation. As a further illustration of the results of such variable legislation, I may state that while engaged in collecting the statistics for this report I saw in the testing room of a large refinery a large table, on which were no less than seven different instruments that were in daily use for testing oils to fill orders from different localities. These instruments included Abel's for the Canada market, Saybolt's for the New York city export market, the Ohio tester for the Ohio market, and a number of others. I doubt if the legislative regulation of any other substance presents such anomalous and contradictory characteristics.

There is but one temperature at which illuminating oils manufactured from petroleum can, when properly tested, give off an amount of vapor sufficient to produce an explosive mixture within the limits of public safety. That temperature alone should be made the subject of legislation, and the testing should be made with whatever instrument gives results that may be repeated with the greatest accuracy. The question of absolute safety has already been discussed; that of comparative economy is outside the domain of legislation.

SECTION 5.—BURNERS.

One other subject deserves consideration in this connection. It is frequently maintained that with proper burners oils are safe that under other conditions are unsafe. While it cannot be denied that some burners are to be preferred to others, it is my belief *that all burners are safe with safe oil.* There is no doubt, however, that very considerable differences obtain between different burners in point of illuminating power, and hence of economy. This was made a subject of research by Mr. C. J. H. Woodbury in 1873. (a) In his report he says:

The comparative worthlessness of the lighter product of petroleum tempts the unprincipled manufacturer to add them to kerosene, making a product which, on account of its extreme volatility, is *cleaner* than pure kerosene; the flame is of greater brilliancy, and, on these grounds, it recommends itself over the pure oil to those who have not been able to give attention to this subject. Many of these compounds are quite as dangerous as gunpowder. As kerosene has been in use only a few years, a sufficient interval has not elapsed to enable us to burn it with the greatest possible economy. * * * The writer, in the following series of experiments upon various kerosene burners, has endeavored to ascertain the most favorable forms of burner for an economical expenditure of oil compared to the light given. The results given for each lamp are the mean of from 150 to 250 observations.

FLAT WICKS.

No.	Chimney.	Wick.	Candle power.	Hours required to consume 1 gallon.	Candle power to gallon.
		Inch.			
1	Bulge	⅝	8.469	99.06	594
2	Bulge	⅝	6.420	127.53	815
3	Bulge	¾	6.587	125.35	823
4	Sun	⅝	5.138	163.93	829
5	Sun	⅝	4.829	171.80	830
6	Sun	½	4.810	174.87	835
7	Bulge	⅝	7.398	115.23	887
8	Sun	⅝	7.371	131.19	964
9	Sun	⅝	5.997	188.57	1,110
10	Bulge	1	10.754	113.17	1,209
11	Bulge	⅞	*19.480	....	....
12	Bulge	½	*10.030	....	....

* As these lamps were made to burn mineral sperm oil, we do not give the results.

CIRCULAR WICKS.

No.	Chimney.	Wicks.	Candle power.	Hours required to consume 1 gallon.	Candle power to 1 gallon.
13	Circular	Circular..	8.387	101.20	833
14	Circular	Circular..	8.824	103.68	911
15	Circular	Circular..	10.905	123.68	1,347

The list could have been made much longer, but it would serve our purpose no better.

The oil used was Downer's kerosene, specific gravity 0.801. One gallon, at 62° F., weighing 3,025.3 grams. The first column of results shows the candle power given by the lamp when burning with a full flame, but below the smoking point. The second gives the number of hours required to consume 1 gallon of oil. The object of the third column is to give the economy of the lamp, by a unit, which is the candle power given by an ideal lamp, exactly similar to the one under observation, with the exception that it shall consume precisely 1 gallon an hour. This result is constant for all except extremely high or low flames. Such a unit is very empirical, but no more so than the modulus of elasticity, or absolute zero. * * *

A simple inspection of the above lamps shows their economical results to be in the direct ratio to the facilities afforded the air for approaching the base of the flame. Where the air cannot enter freely, much of the oil seems to be volatilized without combustion. The best example is given by cases 5, 8, 9, and 10. The lamps are all similar, except in the difference noted below, and are of the pattern generally known as "sun-burners". In the first example, the air must pass through two horizontal brass diaphragms at the base of the chimney; one is pierced with holes ¾ inch in diameter, the other about ₁₆ inch; case 8, one fine diaphragm at base of chimney; cases 9 and 10, the base of the chimney is open; a diaphragm is near the base of the flame. Although the two lamps are different in size, they are identical in principle, the following being the cause of difference in the result: a certain portion of the light is shaded by the top of the burner. This conceals an equal amount (not proportion) of the flame, whether it is high or low. Also, a large flame makes a much more powerful draft than a smaller one. If we have two similar lamps, the larger one will give the best results.

In the four lamps just cited, if we remove the coarse diaphragm from the first lamp we increase its efficiency 16 per cent.; in addition, taking away the fine one, we increase it 18 per cent. more; make the draft more powerful by a bulge chimney, we have a further increase of 12 per cent. Lamps like 9 and 10, from their open construction, are extremely sensitive to currents of air. Lamp No. 3 is a metallic lamp, and very thoroughly constructed. The air is supplied from the base of the lamp, the burner being closed; it is not sensitive to currents of air, and gives the most steady and agreeable flame of any that have come under observation. If the entrance to the air passage was made larger, and the diaphragms in the burner were pierced with larger holes, the efficiency of the burner would be increased greatly, while it would probably retain its steadiness of flame. In lamp No. 15 the air is introduced into the center of the flame with less obstruction than in the two previous cases, and this lamp gave the most economical results.

The results here given show that in the question of the economical combustion of illuminating mineral oils much depends upon the burner. At the special general meeting of the London Petroleum Association, held on January 14, 1879, it was generally admitted that not only the burner, but the wick, played an important part in the successful combustion of petroleum oils. It was also shown on that occasion that a loosely woven wick was preferable to a more solid one, but that with any form of wick or burner oils of inferior quality produced a crusted wick with a smoky flame and heated burner. Judging from the discussion that took place on that occasion, together with my own experience, I conclude that oils that are prepared from petroleum without destructive distillation may be burned with a very slow consumption of the wick, but that the wick used with these oils, in time, through some physical or chemical action which has not yet been investigated, suffers impaired capillarity and becomes unfit for use, although it may still be of sufficient length to reach the oil. Such wicks should be discarded as soon as they give trouble. Burners also should be discarded as soon as they become worn and do not act satisfactorily. The primary question, however, rests with the oil. Cracked oils containing much heavy oil and a comparatively large content of sulphur very soon convert a wick into a charred mass saturated with a gummy substance that partially destroys its capillarity and produces an imperfect combustion and inferior flame. To secure the best results the best oil should be burned in lamps supplied with fresh burners and wicks carefully trimmed.

The fact has been established beyond all controversy *that no combination of lamp, burner, and wick that has ever been invented or can be invented will make an inferior or unsafe oil either satisfactory, economical, or safe.*

Dr. Thomas Cattell writes as follows to an English journal:

It is two years since the first intimation of danger from sophisticated candle-wick was forced on my attention. The candle, a thick dipped one, was placed lighted upon a table, and after a period of about twenty minutes it guttered so violently that the tallow flowed down on to the table around the bottom of the candle-stick, followed in a few seconds by a collapse of the wick, bared of tallow, on to the table, setting fire to the melted tallow. If I had not been present serious consequences would have ensued. When this incident occurred I had not thought the fault lay primarily with the candle-wick; I held the tallow to blame. A recent accident, however, with a large paraffine lamp has brought to light the fact that the medium or wick through which the tallow and the oil are used as sources of light is unsuitable for its object, as well as fraught with considerable danger. Experience has taught that cotton is the one peculiar and valuable medium for supplying the sources of light here referred to. Spurious cotton-wick I believe to be a mixture of cotton and flax waste, or a combination of jute, hemp waste, and cotton. Such wick, or at least the alien portion of it, becomes quickly carbonized both in candles and lamps. With the first, the carbonized particles as they form dart out with a flash or drop on the melted tallow undergoing absorption by the wick, giving rise to guttering and a great waste of tallow. In the other, the ignited portion soon carbonizes, which more and more increases in depth, until a point is reached when further capillarity in the direction of the flame ceases and ignition of the lower part of the wick takes place, followed by that of the oil in the receiver, with explosion or other mishap. I believe it will be found that the danger to which I here allude will afford an explanation of many fires and accidents that, but for these observations, had ever remained involved in mystery. Pure cotton-wick is slow to carbonize, and its consumption is uniform, unaccompanied by sudden little ejections and explosions, as occur in the burning of spurious cotton-wicks previously alluded to. If ordinary paraffine oil be not of the required combustion standard, such wick would greatly increase its danger. Microscopically, flax fiber consists of jointed cylindrical tubes. Cotton consists of flattened twisted tubes without joints. Chemical analysis would give us more or less of the nitrates, nitrites, and binitrites of cellulose. (a)

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a Oil and Drug News, January 31, 1882.

CHAPTER III.—NATURAL GAS AND THE CARBURETING OF GAS AND AIR.

SECTION 1.—OCCURRENCE AND COMPOSITION OF NATURAL GAS.

The occurrence of springs of water accompanied with gas have been noted from a very early period. The number of localities named "burning springs" in different parts of the country attest the wide distribution of this phenomenon. It is, however, very erroneously supposed by some writers that these burning springs are immediately related to volcanoes. Dr. Ansted appears to think that they are closely related to mud volcanoes; but in the United States, east of the Mississippi river, where mud volcanoes are unknown, it appears that gas springs are the product of the same kind of action that has produced petroleum, and they often accompany petroleum. Wall observed in his researches upon Trinidad that—

The phenomena of salses or mud volcanoes, consisting of the solution of inflammable gas, accompanied by the discharge of a muddy fluid and asphaltic oil, is, perhaps, closely related to the activity just described, as carbureted hydrogen may be disengaged in the direct formation of asphalt.

Several of them occur in Trinidad, also in the "Newer Parian". They were likewise observed in the province of Maturin, presenting similar characters. At Turbaco, near Carthagena, precisely the same action is manifested, but on a much larger scale. This is further confirmatory of a great extension of the above formation to the westward. The thermal waters of Trincheras, near Valencia, issuing from mica-schist, contain merely traces of silica, sulphureted hydrogen, and nitrogen, and possess a variable temperature, as shown by the following determinations:

Humboldt, in 1800 .... 194°
Boussingault, in 1823 .... 206°
The author, in 1859 .... 198°

The hot springs of Chaquaranal, near Pilar, in a limestone of the "Older Parian", present the rare phenomena of water discharged at and even above the boiling point. Sometimes the fluid is delivered under pressure, rising in a jet, continuing in a state of ebullition for several feet from the point of discharge, accompanied by a forcible evolution of steam, and depositing abundance of calcareous matter.

The fissures of the adjacent rock are lined with spathose crystallizations and the acicular forms of sulphur. The vapors escaping from these fissures consist principally of steam. (a)

Professor Ansted observed copious discharges of gas, petroleum, and mud from the mud volcanoes of the valley of Pescara, in Italy, and also in the Crimea. I do not, however, interpret these phenomena as volcanic, or as in any manner an association of cause and effect, but rather as associated incidents of the dying out of the metamorphic action which has in most cases by invasion of strata containing organic matter distilled all of the forms of bitumen, including inflammable gas. The observations of Wall confirm this hypothesis in the most striking manner.

In the great petroleum region of the Appalachian system the accumulations of gas are often found upon the anticlinals in the pebble conglomerates and sandstones that hold the petroleum, while at a still lower level in the troughs of the synclinals salt water occurs. In a general manner, with the sea-level as a datum line, the Venango and Bradford oil-sands lie sloping at a gentle inclination, the southwestern edges submerged in salt water, and the northeastern edge saturated with gas under an enormous pressure. Not the slightest evidence that volcanic action ever has obtained in that region has been observed; but all the geological features, which have already been so fully discussed on previous pages of this report, lead to the conclusion that petroleum and natural gas have been produced by the same cause. That volcanic action is not that cause is further shown by a comparison of the analyses that have been made of natural gases from various localities.

In 1876 Professor S. P. Sadtler, of the University of Pennsylvania, examined with great care the gas from four different wells in northwestern Pennsylvania, which was used in all cases for technological purposes. I quote from his paper read before the American Philosophical Society, February 18, 1876, as follows:

Having had occasion lately to analyze some of the gases issuing from wells in western Pennsylvania, I have obtained some results which are given as a contribution to our knowledge of these important natural products. There have been almost no analyses whatever made of these gases. In 1866 a French geologist, M. Foucon, visited a number of these gas-wells and collected specimens of the gases. These were afterward analyzed by M. Fonqué, and the results published in *Comptes Rendus*, lxvii, p. 1045. The localities were Pioneer run, Venango county, Pennsylvania; Fredonia, New York; Roger's gulch, Wirt county, West Virginia; Burning Springs, on the Niagara river below the cataract; and Petrolia, Enniskillen district, Canada West. These points are certainly widely enough removed to make the series comprehensive from a geological standpoint. The analyses do not appear to have been complete ones, as M. Fonqué determined the exact amounts of only a few of the constituents. In general, the gases were composed of the marsh-gas series of hydrocarbons. Thus the gas from Pioneer run he found to have essentially the composition of propyl hydride (C_3H_8), with small quantities of carbonic acid and of nitrogen; the Fredonia gas appeared to be a mixture of marsh-gas (CH_4), and ethyl hydride (C_2H_6), with a small quantity of carbonic acid and 1.55 per cent. of nitrogen; the Roger's gulch gas was CH_4 almost exclusively, with 15.86 per cent. of carbonic acid and a small quantity of nitrogen; the Burning Springs gas almost pure CH_4 with a little CO_2; the Petrolia gas a mixture of marsh-gas

(CH$_4$) and ethyl hydride (C$_2$H$_6$), with a small amount of carbonic acid. However, the composition as given was only apparent, as in the case of the Pioneer run gas, for on passing the gas through alcohol a part was absorbed, which was afterward shown to be butyl hydride (C$_4$H$_{10}$), while the part unabsorbed showed nearly the composition of marsh-gas (CH$_4$). It was evident, therefore, that what appeared to be propyl hydride (C$_3$H$_8$) was in reality a mixture of marsh-gas (CH$_4$) and butyl hydride (C$_4$H$_{10}$).

In 1870 Professor Henry Wurtz made an analysis of the gas from a well 500 feet deep in West Bloomfield, Ontario county, New York. He found:

	Per cent.
Marsh-gas CH$_4$	82.41
Carbonic acid CO$_2$	10.11
Nitrogen N	4.31
Oxygen O	0.23
Illuminating hydrocarbons	2.94
	100.00

The specific gravity of the gas was 0.693

Professor S. A. Lattimore, of Rochester University, New York, examined this gas in 1871, and estimated its flow to be 800,000 cubic feet in twenty-four hours of 14.42 candle power.

The gases which I collected and analyzed were: First, the gas of the Burns well, in Butler county; secondly, that of the Harvey well, in the same county; thirdly, that from the Leechburg well, across the Kiskeminitis river from Leechburg, in Westmoreland county; and fourthly, the gas bubbling from a spring at Cherry Tree, in Indiana county.

He obtained the following results: (a)

COMPOSITION OF THE GAS OF CERTAIN WELLS.

Name of well.	Carbonic acid.	Carbonic oxide.	Illuminating hydrocarbons (C$_n$H$_{2n+2}$).				Oxygen.	Nitrogen.	Specific gravity.	Heating power.	Pyrometric heating power.
			Hydrogen.	Marsh-gas.	Ethyl hydride.	Propyl hydride.					
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.	Per cent.	Deg.
Burns' gas-well	0.34	Trace.	6.10	75.44	18.12	Trace.			0.6148	14,214	2,745
Leechburg gas-well	0.35	0.26	0.56	89.65	4.39	Trace.			0.5580	14,105	2,746
Harvey gas-well	0.66	Trace.	13.50	80.11	5.72	Trace.			0.5119	15,597	2,763
Cherry Tree gas-spring	2.28		22.50	60.27	6.80		0.83	7.32			

The following results were obtained from the analysis of the gas escaping from a well in Belfast, Ireland. It passed through 33 feet of silt and 7 feet of gravel containing organic *débris*. The gas escaped from the gravel. Its density was 0.661, air = 1, inodorous, and contained no compounds of carbon and hydrogen, except CH$_4$. Its composition was found to be—

	Per cent.
CH$_4$	83.75
CO$_2$	2.44
O	1.06
N	b 12.75

An analysis is here given of the gas of the Burning Spring of Saint Barthélemy (Isère): (c)

	Per cent.
CH$_4$	98.81
CO$_2$	0.58
N	0.48
O	0.10
Loss	0.03
	100.00

The results of several analyses of the gases escaping from the solfataras and fumaroles, given below, will be found to exhibit a strikingly different composition. The first is an analysis of the gases rising through the Lago di Naftia in the Val del Bove of Etna:

	I. Per cent.	II. Per cent.
CO$_2$	94.23	84.58
H$_2$S		6.17
CH$_4$	1.82	2.42
O	0.28	4.52
N	3.79	1.89

Neither acetylene nor olefines were present. (d) The next is an analysis of the gases evolved from fumaroles on the island of Saint Paul. The temperature was 78°–80°: (e)

	Per cent.
CO$_2$	14.24
O	17.01
N	68.75

a *American Chemist*, vii, 97; W. B., 1876, p. 1134.
b C. N., xxx, 136; J. C. Soc., xxviii, 242.
c *Mont. Sci.*, 1870, p. 550; W. B., 1870, p. 704.
d *Gaz. Chim. Ital.*, ix, 404; J. C. S., xxxviii, 345.
e *C. Rendus*, 1875, No. 7.

The gas from Campi Flegrei, Vesuvius, is not constant in composition, but is mainly CO. H_2S is about 5 per cent., O less than 1 per cent., N 5 to 10 per cent., sometimes as high as 50 to 60 per cent., with occasionally a small quantity of CH_4. The Grotto del Cane yields pure CO. (a) No combustible gases are evolved by the Caldeira de Fumas, San Miguel, Azores, differing in this respect from the geysers of Iceland and the Suffoni of Tuscany, both of which invariably contain H and CH_4. (b) The gases from Santorin, after the eruption of 1866, contained CO_2, O and N in constantly varying proportions, with traces of H, H_2S, and CH_4. In 1870 HCL and SO_2 were present. (c) The gases evolved from solfataras contain CO_2, H_2S, O, and N. Two of them yielded wholly CO_2. The Great Solfatara yields steam, H_2S, CO_2, O, and N. (d)

A comparison of these results of analysis shows the great difference between the constituents of the gases from these two sources. In the gases from Burning Springs CH_4 predominates, accompanied by other products of *distillation;* in the gases from solfataras CO_2 predominates, accompanied by other products of the *combustion* of carbon. The distillation of strata rich in organic remains, when invaded by metamorphic action, has doubtless produced the inflammable gases of burning springs and gas-wells in a manner analogous to and often simultaneous with the production of petroleum.

In the United States the phenomena of burning springs were observed by the earliest settlers west of the Alleghanies. Dr. Hildreth described these springs as they occur in the valleys of the Little and the Great Kanawha, in West Virginia, in 1833, and later in the valley of the Big Sandy, in Kentucky. The volume of gas escaping from these springs is often remarkable, but no attempt was ever made, so far as I can learn, in any manner to utilize this material. The boring of wells for salt and petroleum led to the frequent penetration of strata heavily charged with gas that was destitute of petroleum. This was most frequently the case on the borders of petroleum fields in rocks that were, relative to the sea-level, higher than those yielding oil. The localities that have been and are most noted for their gas-wells are: Fredonia, Chautauqua county, New York; Wilcox, Elk county, Pennsylvania; Rochester, Beaver county, Pennsylvania; Burns well and Harvey well, Butler county, Pennsylvania; Leechburg, Westmoreland county, Pennsylvania; Sheffield, Warren county, Pennsylvania; Allegheny county, Pennsylvania; Erie, Erie county, Pennsylvania; Painesville, Lake county, Ohio; East Liverpool, Columbiana county, Ohio; Gambier, Knox county, Ohio; New Cumberland, Hancock county, West Virginia; Burning Springs, Wirt county, West Virginia.

The gas from wells at several of these localities has been made very valuable for technological purposes:

The use of natural gas at Fredonia was begun in 1821, and was introduced into a few public places, among which a hotel was illuminated when General Lafayette passed through the village. The gas from this well, which was sufficient for about thirty burners, was used alone until about 1858, when another well was drilled, which supplied some two hundred burners. Another well was drilled in 1871 with better success. The average monthly supply of the three combined is about 110,000 cubic feet, of which an average of 80,000 cubic feet per month is consumed for lights. Seven other wells, varying from 50 to 800 feet deep, have been made without success. The area covered by these wells is about one mile in length by one-half mile in width. The supply has not perceptibly diminished since the opening of the wells. (e)

At Erie, Pennsylvania, gas-wells have been bored along Mill creek. Some of the deepest of these wells have yielded a dense oil. The Demming well struck gas at about 440 feet under such a pressure that it blew oil to the top of the derrick for twenty-four hours. Many gas-wells have been drilled for private dwellings and manufacturing establishments. For the latter purpose, where large quantities are used, the yield of the wells runs down in a few years. At Painesville, Ohio, gas-wells are bored for private dwellings, and the gas is used often for heating as well as for illuminating purposes. At Rochester, Pennsylvania, and East Liverpool, Ohio, the gas is burned in enormous quantities in glass houses. At Gambier, Ohio, and New Cumberland, West Virginia, the gas is burned in a manner to produce lampblack. The gas of the Burns, Harvey, and Leechburg wells is or has been used in puddling iron. The latter was found particularly valuable in the preparation of the quality of pure rolled iron used for tin plate. The Sheffield well was bored for oil, but instead of oil it has discharged a jet of gas that has burned continuously for five years. In the oil regions the gas from these wells is frequently burned in the open air for no other purpose than to prevent the formation of dangerous explosive mixtures of gas and air.

Bradford and other towns in the oil regions are mainly heated and lighted with natural gas from the oil-wells, and in some instances from wells drilled on purpose to obtain gas. If no oil accompanies the gas, the flame is clear and white, but if oil is present it is red and smoky. Benzine often condenses in the pipes from natural gas, and it is not unreasonable to suppose that, at the enormous pressure under which this gas is held in the oil-sand, the gas is condensed to a liquid. In the Bradford region especially this pressure is much too great to be ascertained by pressure gauges, and has often been made a subject of conjecture, rather than of estimate, as equaling from 2,000 to 4,000 pounds per square inch. Any attempt to ascertain the pressure would be attended with the risk of having the casing and tubing thrown out of the well. The evaporation due to the removal of this pressure produces an extraordinary reduction of temperature. At Sheffield the temperature fell so low that ice formed in the well pipe and finally closed it. The ice was then drilled through 100 feet in depth. When it was pierced, the pressure threw

a C. Rend., lxxv, 154; J. C. Soc., xxv, 884.   d Ann. de Ch. et de Phys. (4), xxv, 559; J. C. Soc., xxv, 469.
b Ibid., lxxv, 115; Ibid., xxv, 885.   e Letter of E. J. Crissey, secretary of the Fredonia Natural Gas-light Company, to S. F. P.
c Ibid., lxxv, 270; Ibid., xxv, 885.

the tools and well casing out of the top of the derrick. When a stratum yielding gas is struck in boring, the force of the escaping gas prevents water from reaching the bottom of the well if poured down the side, or even, in some cases, if introduced from a tank through a pipe reaching to the bottom. In most cases by this latter arrangement (which gives the weight of a column of water several hundred feet in height) the gas is "stopped off". The gas has been used in several instances to work an engine for pumping without water or heat by introducing it into the cylinder, precisely like high-pressure steam. In drilling the Roy well, near Kane, Pennsylvania, the gas from a well more than one-fourth of a mile distant was used in this manner. It is very frequently used as a fuel for making steam, and, when there is a surplus, that is burned at the end of a pipe to prevent explosions. The greatest gas-well on record in the oil regions is the Newton well on the Nelson farm, 6 miles north of Titusville. There the gas raised a column of water 100 feet high with a noise that could be heard 2 miles, and when the column burst it threw the water 15 rods each way.

The Bradford Gas-light and Heating Company receive gas into a gasometer from wells near the city. Two sets of pipes pass through the city. One set passes from the wells to the gasometer, and has the same pressure as that on the wells; the other set passes from the gasometer, and delivers the gas under a pressure of about 6 inches of water. Gas is delivered from both sets of pipe; from the high pressure for boilers, etc., and from the other set for use in dwellings. The mains attached to the wells will deliver through the same orifice about ten times the amount delivered from ordinary street mains. The wells are so deep that the friction on the escaping gas is very great, and retards the motion and lowers the pressure as it escapes. The pressure at the wells gradually diminishes. In one case it ran down from an estimated pressure of 1,000 pounds to 6 pounds in five years. When first struck the gas would easily have lifted the casing out of the well, requiring a force of at least 500 pounds per square inch. It was estimated that during the month of January, 1881, 7,500,000 cubic feet of gas reduced to ordinary pressure were delivered in Bradford, where it is almost universally used for heating as well as for illumination. The burning of the superfluous gas at nearly all the wells forms at night great flaming torches, that glare in the darkness from the surrounding hillsides.

Mr. Charles A. Ashburner, of Philadelphia, has described a well which has received the name of the "Kane geyser well". It is situated 4 miles southeast of Kane, on the Philadelphia and Erie railroad. While drilling—

Fresh "water-veins" were encountered down to a depth of 364 feet, which was the limit of the casing. At a depth of 1,415 feet a very heavy "gas vein" was struck. This gas was permitted a free escape during the time the drilling was continued to 2,000 feet. When the well was abandoned, from failure to find oil, and the casing drawn, the fresh water flowed in, and the conflict between the water and the gas commenced, rendering the well an object of great interest. The water flows into the well on top of the gas until the pressure of the confined gas becomes greater than the weight of the superincumbent water, when an explosion takes place and a column of water and gas is thrown to a great height. This occurs at present at regular intervals of thirteen minutes, and the spouting continues for one and a half minutes. On July 31 (1879) Mr. Sheafer measured two columns, which went to a height respectively of 120 feet and 128 feet. On the evening of August 2 I measured four columns in succession, and the water was thrown to the following heights: 108 feet, 132 feet, 120 feet, and 138 feet. The columns are composed of mingled water and gas, the latter being readily ignited. After nightfall the spectacle is grand. The antagonistic elements of fire and water are so promiscuously blended that each seems to be fighting for the mastery. At one moment the flame is almost entirely extinguished, only to burst forth at the next instant with increased energy and greater brilliancy. During sunshine the sprays form an artificial rainbow, and in winter the columns become encased in huge transparent ice chimneys. A number of wells in the oil regions have thrown water geysers similar to the Kane well, but none have attracted such attention. (a)

Some of the most remarkable gas-wells that have ever been drilled outside the oil region are the Neff gas-wells near Gambier, Knox county, Ohio. These wells are located on the Kokosing river, a tributary of the Walhonding river, which empties into the Muskingum above Zanesville.

No. 1 well is sunk not far from the line of Knox and Coshocton counties. Such a powerful vein of rich illuminating gas was struck as to cause suspension of all work. From this well immense floods of water, in paroxysms of about one minute interval, are thrown up to a height of 80 to 100 feet. The vein of water was struck, fortunately, at a depth of only about 66 feet, where a large stream was tapped, producing no inconvenience in boring until the gas was struck, when suddenly it was all discharged at regular intervals of not more than one minute. The boring throughout its whole length of 600 feet is filled and discharged, making a most magnificent hydraulic display. It is, however, at night that the grand phenomena of this well are best exhibited. The enormous amount of water, perhaps 10,000 barrels per day, keep the derrick and floor so wetted that the gas can be fired with safety. When this is done, at the instant of paroxysm a sudden roar is heard, and at night the flame is seen shooting up 15 to 20 feet above the derrick, which is 53 feet high. It is a grand sight to see the flame leaping fiercely amid the rushing waters, darting out its fiery tongues on every side; now rolling above the most powerful part of the jet like balls dancing on a fountain, and now, with an intensely bright flame, leaping suddenly down the column and running along the floor, and illuminating, as with burning liquid naphtha, which is undoubtedly thrown out with the water, the whole forest scenery around as a magnificent spectacle. When the derrick was covered with ice the gas escaping from the well was frequently ignited, and the effect, especially at night, of this fountain of mingled fire and water shooting up to the height of 120 feet through a great transparent and illuminated chimney is said to have been indescribably magnificent. (b)

A phenomenon (called a gas volcano) that has been observed in the valley of the Cumberland, in southern Kentucky, near Burkesville, is thus described. In a private communication Dr. J. S. Newberry writes:

This name is given to explosions of gas accumulated under the flaggy rocks of the Hudson River group in the valley of the Cumberland and its tributaries. I have visited localities where explosions have occurred, but have never witnessed one myself. They result from the confinement of gas generated below under impervious strata of rock, the pressure ultimately becoming sufficient to throw off the superincumbent mass of rock, earth, water, etc. These explosions are not very uncommon in the valley of the Cumberland, and they are well known to the inhabitants.

a Jour. Frank. Inst., cviii, 347.   b Prospectus of the Neff Petroleum Company, 1866.

Section 2.—USE OF NATURAL GAS IN THE MANUFACTURE OF LAMPBLACK, ETC.

The gas of the Neff and other wells is largely utilized for the production of lampblack. This black is of very superior quality, and when first produced and thrown upon the market commanded as high a price as 75 cents per pound, but the production was very soon increased so largely in comparison with the demand that the price is now only about 15 to 20 cents per pound. Concerning the production of lampblack from natural carbureted hydrogen, a writer in Dingler observes as follows : (a)

It is known that gases escaping from the soil of some of the oil districts of Pennsylvania (compare 1878, 228, 534) is prepared for illumination and heating purposes (1877, 224, 552). P. Neff now produces from the same by imperfect combustion an excellent lampblack, which he brings into market under the name of "diamond black". This gas flows from two wells which are bored at Gambier (Knox county, Ohio), in the vicinity of the mouth of the Kokosing. According to J. R. Santos (Chemical News, 38, 94, 1878), it has the following composition :

	Per cent.
Marsh-gas	81.4
Ethylene	12.2
Nitrogen	4.8
Oxygen	0.8
CO	0.5
CO_2	0.3
	100.0

Neff burns daily with 1,800 burners of peculiar construction almost 8,000 cubic meters of gas and obtains from it 16 per cent. of lampblack. The specific gravity of this lampblack is, according to Santos, 1,729 at 17° C. Dried at 200° an elementary analysis gives:

	I. Per cent.	II. Per cent.
C	96.041	96.011
H	0.736	0.747

By means of Sprengel's air-pump the gas is pumped out, having the following composition:

CO	1.387
CO_2	1.386
N	0.776
H_2O	0.682

Besides, 0.024 per cent. of a bright yellow hydrocarbon soluble in alcohol, and which boils at from 215° to 225°, is obtained, which is probably impure naphthaline. The small quantity of ashes consisting of the oxides of iron and copper comes from the burners. The united composition of diamond black is accordingly as follows:

	Per cent.
C	95.057
H	0.665
N	0.776
CO	1.378
CO_2	1.386
H_2O	0.682
Ashes	0.056
	100.000

The black is consequently very pure, and in any case is well adapted for fine printers' ink and the like. It is also used in the preparation of lithographic ink.

At New Cumberland, Hancock county, West Virginia, Messrs. Smith, Porter & Co. use natural gas for burning fire-brick. The gas from one well furnishes fuel for nine brick kilns, three engines, and ten furnaces in the drying house, with fuel and lights for several dwellings, besides a large excess that is burned at the end of an escape pipe. They produce 55,000 brick daily.

Section 3.—GAS FROM CRUDE PETROLEUM, PARAFFINE OIL, AND RESIDUUM.

A large number of patents have been taken out for processes and apparatus for the manufacture of illuminating gas from crude petroleum and the dense products of its manufacture. The general principle upon which all of these processes depend for operation consists in a distillation of the materials at a temperature sufficiently elevated to crack the petroleum compounds into gaseous products. The "gas oil", which is petroleum deprived of its naphtha, is conducted into a retort previously heated to a red heat. The method of heating the retort, the manner of distributing the fluids, and the purification of the gas from the undecomposed petroleum and tarry matters, are all subject in the different patents to differences of arrangement, but the underlying principle of destructive distillation is fundamental in all of them. This method of preparing illuminating gas is quite extensively used for lighting large manufactories and villages and small towns. It is especially valuable for these purposes on account of the comparative simplicity of the apparatus and process of manufacture and the purity of the product. The gas prepared by this method is particularly free from the ammonia and sulphur compounds that contaminate gas prepared from coal.

a Dingler, ccxxxi, 177.

Section 4.—GAS FROM NAPHTHA.

Gas is also prepared by the destructive distillation of petroleum naphthas and benzine. One of the methods of operating this process is thus described: A still holding 40 barrels of naphtha contains a coil of 2-inch pipe; steam passes through the coil, volatilizing the naphtha, the pressure carried on the still being on an average about one-half inch. The vapor passes to three benches, of three retorts each, by a 3-inch pipe; 1½-inch branches to each retort are tapped into the side of this mouth-piece, connecting with a 6-inch cast-iron pipe, which lies inside of the retort to within 1 foot of the back, and is open at the back end, but plugged in front with a clayed stopper. The vapors circulate through the 6-inch pipe to the back end of the retort and return forward and up the stand-pipes, which are 6 inches in diameter. These retorts are heated to dull redness. During this transit the vapors of naphtha are converted into gas and pass through a submerged U-shaped condenser, 18 inches in diameter, lying in a tank with sufficient inclination for a drip. An air-pump is used to preserve an exhaust of about 3 inches, from which the gas passes to a station meter and "mixer". At every revolution of the station meter 42 per cent. of air is drawn in by a reverse drum on the same spindle, and is mixed with the gas, which thence passes to the holder. The introduction of air is not necessary, as the gas can be burned with a suitable burner; but the gas thus prepared is very rich, and the air is introduced to reduce its quality to the average standard of 15 or 20 candle-power. It will be observed that all apparatus for purifying the gas is dispensed with, the gas being entirely free from all deleterious sulphur and ammonia compounds. The only residue in this process is a small quantity of heavy oil, apparently a residue from the cracking of the benzine.

Section 5.—CARBURETORS.

The idea of saturating illuminating gas with the vapors of volatile hydrocarbons for the purpose of increasing its illuminating power was entertained long before the discovery of petroleum in commercial quantities.

Lowe patented a process in 1841, and alluded to it in a general way in a previous patent of 1832, the claim in which is so comprehensive that, if valid, it would render doubtful all subsequent patents. (a) Mansfield also claimed the application of atmospheric air as a vehicle for the vapor of very volatile hydrocarbons in such a manner that the "vaporized air" might be burnt like ordinary coal-gas. (b)

As early as 1856 Longbottom attempted to prepare illuminating gas by passing air through benzole, ether, or oil of turpentine. (c) These appear to be the earliest attempts at carburation. These machines were never made a practical success, however, until the distillation of petroleum furnished volatile hydrocarbons in commercial quantities. The low price at which these products could be obtained after petroleum became extensively produced led to the invention of a large number of machines in a great variety of form and principle of construction. The number patented in England, France, Germany, and the United States prior to 1880 must be in the neighborhood of 1,000. The first patents that were issued were for inventions that produced a partial or a complete saturation of the gas or air without in any manner controlling the evaporation or the temperature. The result of the operation of these machines was invariably an overcharging with vapor in warm weather or when the apparatus was first put in action, causing subsequent condensation of the vapor, followed by undercharging as the naphtha was distilled and the residue became less volatile, and as it also was rendered more dense in consequence of the reduction of temperature resulting from the evaporation. Evaporation was induced and rendered more constant and rapid by the construction of a sort of labyrinth through which the gas or air was forced. The tank containing the naphtha was made shallow and of large diameter, and curtains of flannel were so arranged that the upper border of the curtain was securely fastened to the under surface of the cover of the tank and allowed to hang freely, dipping into the naphtha below. As a result, the gas was forced to pass through the spaces between these curtains, and a great evaporation and absorption of the naphtha vapor by the gas followed. This method of carburation, while very effectual, was still open to the objections above made, and did not furnish uniform results; but the difficulty was removed by an invention by which the tank in which the naphtha was being distilled was submerged in a wooden tank of water. The great latent heat of water caused it to give out heat, equalizing the temperature, producing a uniform distillation, and consequently a uniform partial saturation of the gas or air. This contrivance may be said to have rendered the carbureting of air a success, and a large number of machines have been constructed upon this principle. The general arrangement of the apparatus has been a wooden tank, sunk in the ground outside the building and below the frost. In this tank the receptacle for the gasoline is placed, and the intervening space is nearly filled with water. At this depth the water preserves nearly a uniform temperature at all seasons, and from its large volume it compensates the gasoline for its loss of heat due to evaporation, and keeps both the temperature and the distillation uniform; consequently the amount of combustible material supplied the current of air is uniform. This current is forced through the labyrinth by an air-pump worked by a heavy weight, and placed in the basement of the building to be lighted. This form of carburetor is entirely free from the grave defect of starting at the beginning of the evening with an excessive evaporation and ending at 10 or 12 o'clock with an insufficient evaporation. The distillation proceeds uniformly, and changes in quantity gradually, the difference being perceptible only after the machine has been in operation several weeks or months. The gradual fractional distillation results in the accumulation of a residue in the labyrinth too dense for evaporation with

a Jour. Soc. Arts, ii, 503.   b Ibid., 520.   c Jahresbericht, 1856, p. 422.

sufficient rapidity to properly carburet the air, and is, consequently, attended with diminished illumination. Many attempts have been made to remedy this defect, in which great success has been attained by a remarkable invention of very recent date. This machine is called the metrical carburetor, and is used for carbureting either gas or air. The name designates a peculiar feature of the instrument—that it *measures* the amount of carbureting fluid to either the gas or the air; hence there is never an excess of carburation, no fractional evaporation, and no condensation of liquid in pipes. One and one-half to 2 gallons of light naphtha are measured to 1,000 cubic feet of ordinary street gas, or 3 to 6 gallons of gasoline to 1,000 cubic feet of air, according to the purpose for which the gas is to be used.

The carburation of gas and air has been made the subject of many elaborate researches. Prominent among those who have conducted them is the late Dr. Henry Letheby, medical officer of health to the city of London, who, as early as 1861, reported that—

With regard to the carbureting process we are of opinion, from the data obtained by the laboratory experiments quoted in the report to the commission of the 30th of July last and the experiments made on the public lamps in Moorgate street during the months of June and July last, that the process of carburation appears to be capable of economizing the use of gas in the public lamps to the extent of from 40 to 50 per cent. This conclusion is founded on the assumption that the best quality of naphtha is to be used, namely, a naphtha which will give to the gas continuously a proportion of about 10 grains of volatile hydrocarbon to each cubic foot of gas, these being the average results of the laboratory experiments. (*a*)

The following comparative tests were published in 1879 in *Engineering*, but the author is not mentioned:

PRACTICAL TEST.—Barometer, 29.8; temperature, 56°; the weight of gasoline, 655 grains to water 1,000 grains; therefore one gallon of gasoline = 45.850 grains. The air was simply aspirated at the rate of 6 cubic feet per hour through an ordinary chemist's wash-bottle, and each cubic foot took up 735 grains, illuminating gas of 17.10 candles taking 585 grains.

$$\frac{1,000 \text{ cubic feet of air} = 735.000 \text{ Grains.}}{1 \text{ gallon of gasoline} \quad = 45.850} = 16.0 \text{ gallons of gasoline per 1,000 cubic feet of air.}$$

$$\frac{1,000 \text{ cubic feet, } 17.10 \text{ gas} = 585.000}{1 \text{ gallon of gasoline} \quad = 45.850} = 12.7 \text{ gallons of gasoline per 1,000 cubic feet of gas.}$$

One thousand cubic feet of air, after being carbureted, = 1,320 cubic feet; and 1,000 cubic feet of 17.10 gas, after being carbureted, = 1,270 cubic feet.

SPECIFIC GRAVITY TEST.—The time required to pass equal volumes of air, gas, carbureted gas, and carbureted air, under equal pressure, through the same aperture (Shilling's test), was: air, 88 seconds; gas, 58 seconds; carbureted gas, 90 seconds; carbureted air, 104 seconds.

$$\text{Gas, } \frac{58^2}{88^2} = 434 \text{ to air 1,000.}$$

$$\text{Carbureted gas, } \frac{90^2}{88} = 1,045 \text{ to air 1,000.}$$

$$\text{Carbureted air, } \frac{10}{6 \text{ 8}} = 1,396 \text{ to air 1,000.}$$

PHOTOMETRIC TEST.—Test on Hartley's improved photometer, 15-hole argand burner (old standard), 7-inch by 2-inch chimney, consuming 2.4 cubic feet per hour of carbureted gas, = 14.59 standard candles; reduced to the standard of 5 cubic feet, = 37.78 standard candles.

Also, with No. 1 steatite bat-wing, consuming 2.40 cubic feet per hour, = 18.63 standard candles; reduced to the standard of 5 cubic feet, = 38.83 standard candles; 3.48 cubic feet per hour of carbureted air consumed through argand burner = 16.52 candles; reduced to the standard of 5 cubic feet, = 23.70 candles.

DURABILITY TEST.—The durability of 1.10 cubic feet 4-inch flame:

	Min.	Sec.
Gas	5	45
Carbureted gas	16	38
Carbureted air	11	24

Various forms of machines were experimented on, viz, cylinders containing lamp cotton, sponge, felt, and wood carbon. They are all useless and obstructive, nor do they yield so high or regular a light as air aspirated or exhausted through gasoline and charged into a gas-holder, from which it is supplied ready for use at the burner when required.

Upon this the editor of the *Journal of the Franklin Institute* comments as follows:

Two great objections still exist to the use of these machines, viz, the impossibility of storing large quantities of gasoline without the risk from fire to property in the neighborhood; and, secondly, that if the pressure becomes excessive the flame from the burner will be blown out, and terrible explosions, resulting in loss of life, have followed in consequence. The increase in the illuminating property of coal-gas as ordinarily furnished, when passed through these machines, is very great, and the flame, also, is not liable to be blown out with increased pressure; and a wide field seems to be open in this direction if all danger from fire in the carbureting of the gas could be done away with. (*b*)

The value of the metrical carburetor will be appreciated when it is understood that it gives a degree of carburation perfectly satisfactory for gas with 1½ to 2 gallons of light naphtha to 1,000 cubic feet of gas, and for air with 3 to 6 gallons of *gasoline* to 1,000 cubic feet of air. Moreover, this quantity is *measured* to the gas or air with great accuracy, is all immediately absorbed, and, as no supersaturation ever occurs, no condensation ever takes place in the pipes, and no "running down of the light" is ever due to cold nights or distillation of the gasoline. In regard to economy, safety, and perfect operation this metrical carburetor far excels all others hitherto invented.

CHAPTER IV.—THE USE OF PETROLEUM AND ITS PRODUCTS AS FUEL.

SECTION 1.—THEORETICAL CONSIDERATIONS.

The excessive production of petroleum in some localities, and the scarcity of coal and wood in others where petroleum abounds, has led to a large number of experiments in the use of petroleum as fuel. The theoretical consideration of its value as fuel was made the subject of elaborate investigations at an early date. In 1864 R. Mallett stated that—

The theoretical evaporating power of American petroleum may be ascertained as follows:

$$\frac{\begin{array}{c} C\ 86 \\ H\ 14 \end{array}}{100} = 18.06 \text{ kilograms.}$$

For—

$$C\ 0.86 \times 8.080 = 6948$$
$$H\ 0.14 \times 34.462 = 4824$$
$$\overline{11772} \text{ heat units.}$$

$$\frac{11772}{652} = 18.06$$

Regnault's formula is 65.2 heat units for the evaporation of 1 kilogram of water at 0° to steam at 150°. (a)

In 1869 Henri St. Claire De Ville conducted an elaborate research upon the calorific power and physical peculiarities of petroleum. His results are given in the following table:

Locality of the oils.	Specific gravity.	Calorific power.	Locality of the oils.	Specific gravity.	Calorific power.
1. Heavy oil from White Oak, West Virginia; well, 135 meters deep; lubricating oil.	0.873	10.180	10. Oil from Java, commune Tjibodas-Fanggah, district Madja, residency Cheribon.	0.823	9.593
2. Light oil, from Burning Springs, West Virginia; well, 220 meters deep; illuminating oil.	0.8412	10.223	11. Oil from Java, commune Gogor, district Kendong, residency Karabaya.	0.972	10.183
3. Light oil, from Oil creek, Pennsylvania; well, 200 meters deep; illuminating oil.	0.816	9.963	12. Oil from Bechelbronn, upper Rhine, distilled.	0.912	9.708
4. Heavy oil, from Ohio.	0.887	10.390	13. Oil from Bechelbronn, raw.	0.892	10.020
5. Heavy oil, from the Plummer farm, Franklin, Pennsylvania; well, 200 meters deep; lubricating oil.	0.886	10.672	14. Oil from Schwabweiller, lower Rhine.	0.861	10.453
6. American petroleum, as offered for sale in Paris, probably from Pennsylvania.	0.820	8.771	15. Oil from east Galicia.	0.870	10.005
			16. Oil from west Galicia.	0.885	10.231
7. Heavy coal-oil, from the Paris Gas Association.	1.044	8.916	17. Raw schist oil, from Vagnas, Ardèche.	0.911	9.046
8. Petroleum from Parma, near Salo.	0.786	10.121	18. Raw schist oil, from Autun, manufactured by Champeaux, Bazin & Radary.	0.870	9.950
9. Oil from Java, commune Daudang-Llo, district Timanacon, residency Pembang.	0.923	10.831	19. Heavy *Kiefernharz* oil, from Mount de Marzan.	0.985	*10.081

* *C. Rendus*, lxvi, 442; lxviii, 349; C. N., 1869, 237.

In 1871 he examined the petroleums of the Russian empire from the neighborhood of Baku, on the Caspian sea, and obtained the following results: No. 1 was crude naphtha from the Balchany wells, specific gravity at 0°, 0.882; No. 2 was residuum from the Baku stills, specific gravity 0.928; No. 3 was black oil from the Weyser refinery at Baku, specific gravity 0.897; No. 4 was light oil of Baku, specific gravity 0.884; No. 5 was heavy oil of Baku, specific gravity 0.938. On distillation they afforded:

Temperature.	1.	2.	3.	4.	5.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Volatile at 100° C	1.0				
Volatile at 140° C				2.7	
Volatile at 160° C	5.0			7.0	
Volatile at 180° C	9.3			13.3	
Volatile at 200° C	14.0		2.3		1.0
Volatile at 220° C	15.3			19.0	1.3
Volatile at 240° C		1.0	8.0	23.3	1.7
Volatile at 260° C	29.0	2.3	14.0	29.3	3.9
Volatile at 280° C	37.0	4.3	22.3	36.7	6.0
Volatile at 300° C	41.3	7.7	33.7	73.3	9.7

COMPOSITION AS GIVEN BY ANALYSIS.

	1.	2.	3.	4.	5.
Hydrogen	12.5	11.7	12.0	13.6	12.3
Carbon	87.4	87.1	86.5	86.3	86.6
Oxygen	0.1	1.2	1.5	0.1	1.1
	100.0	100.0	100.0	100.0	100.0

a *Pract. Mech. Jour.*, March, 1864, p. 314; Dingler, clxxii, 71.

From these data their calorific power was calculated and compared with that obtained by experiment in the petroleums marked 4 and 5. The results are thus given in calorics:

	1.	2.	3.	4.	5.
Calorific power, calculated	11.370	11.000	11.060	11.660	11.200
Calorific power, observed	(11.070)	(10.700)	(10.760)	11.460	10.800

Numbers 1, 2, and 3 were calculated from the results in 4 and 5. These results show the Baku oils to be superior to those of America and Europe for heating purposes. (a)

In 1877 K. Lissenko stated that—

Some forms of petroleum that yield a less amount of heat on combustion than that calculated are regarded as containing hydrocarbons of the series C_nH_{2n+2}, accompanied by small quantities of non-saturated hydrocarbons. (b)

Later, M. Berthelot has shown in a research upon the gaseous hydrocarbons that the heat of combustion of an hydrocarbon is not always equal to that of its elements. The variation is least in the case of the saturated hydrocarbons C_nH_{2n+2}. (c)

As no two petroleums from different localities are alike in composition, these researches indicate that considerable variation exists in the heating power of different petroleums, and that practically their heating power is considerably less than would be calculated from their elementary composition.

SECTION 2.—PETROLEUM AS A STEAM FUEL.

The employment of petroleum as a steam fuel has been the subject of many experiments and much controversy. From a careful survey of the subject I conclude that no important practical difficulty has been anywhere encountered where for any reason petroleum has been a more desirable fuel than other material. Petroleum has always been burned for steam fuel more or less in the oil regions of Pennsylvania. All sorts of experiments have been made there to burn the crude oil, both pure and mixed, with steam. Mr. D. A. Wray, on Oil creek, filled with crude oil, at 50 cents per barrel, an 8-horse boiler, with safety-valve attached. He fired up under it as if it was filled with water, and burned the vapor as if it were gas. The arrangement worked well until the spaces between the boiler tubes became choked with coke. This deposit of coke from distillation of the oil has been found to be the chief practical difficulty, and has usually been avoided by injecting steam through the escaping oil in such a manner as to completely volatilize it. Another practical difficulty observed by Mr. Wray was explained by him as in accord with an observation of Tyndall that the flame of a Bunsen lamp is intensely hot to objects immersed in it, but that it radiates comparatively little heat. Mr. Wray has observed that all successful contrivances for burning petroleum must distribute the flame *upon* the surface to be heated, and not beneath it. Inattention to this condition is the cause of many unsuccessful attempts to generate steam by the use of crude petroleum. It is impossible that I should attempt to describe the great number of apparatus devised for burning the crude oil, many of which are entirely adequate. The successful use of the oil for years in stationary engine boilers has demonstrated the absence of all serious practical difficulties. The questions of economy and safety appear to have determined that for *general* use it is not a desirable fuel, while in special cases its use has been attended with complete satisfaction.

Mr. William T. Scheide has communicated to me the following results obtained by the United Pipe-lines:

The oil was burned with a steam jet under four stationary boilers (60-inch shells 14 feet long, with 83 3-inch tubes), and the steam furnished a Worthington compound duplex pump doing an *actual* work of about 200 horse-power. (The indicated horse-power would probably be about 225 to 250 horse-power.) These boilers and this pump use as nearly as possible 4.54 pounds of bituminous coal per horse-power of *work done* per hour. Using this average, which is pretty well determined, as a basis, 1 ton of 2,000 pounds of this coal is equal as fuel to either 3.94 or 4.13 barrels of 42 gallons each of oil. The experiment was not conducted as it should have been, and there is a question as to the pressure against which the pump worked, which accounts for the difference in the estimate. I think it may be stated, however, that 4 barrels of oil would be required to furnish the equivalent of a ton of good bituminous coal if the oil is burned with a steam jet. With an air jet I look for better results.

It has also been very thoroughly tested for use on steam vessels. In 1868 the then Secretary of the Navy reported that the appropriation of $5,000 for testing petroleum as a fuel on steam vessels had been expended on a series of elaborate experiments at the New York and Boston navy-yards.

The conclusion arrived at is, that convenience, comfort, health, and safety are against the use of petroleum in steam vessels, and that the only advantage thus far shown is a not very important reduction in bulk and weight of fuel carried.

At Woolwich experiments were made with naphthaline, creosote, residuum, tar, and grease, but nothing proved satisfactory except pure American petroleum and "clear British shale oil". Comparative tests showed the—

	Per cent.
Highest evaporation of water per pound of coal	7.33
Lowest evaporation of petroleum	12.02
Highest evaporation of petroleum	13.00

On July 31, 1869, a train arrived safely in Katschujan, 81 versts from Charkoff, whose engine was heated with raw naphtha (petroleum) instead of coals. The honor of the invention is ascribed to the mining engineer, Portski.

a C. Rendus, lxxii, 191; lxxiii, 491.

b Russian Chem. Soc., June, 1877; C. N., xxxv, 180; J. C. S., xxiv, 453.

c C. Rendus, xc, 1240; J. C. S., xxxviii, 786.

Two engines on the Strasbourg line, fitted in 1870 with M. Deville's furnaces, burn from $3\frac{1}{2}$ to 5 kilograms of oil to every kilometer traversed, or say 8—12 pounds to two-thirds of a mile. The oil is completely burned, and no sulphur is observed in the atmosphere of the tunnels.

Petroleum has also been used with entire success upon steamers and locomotives in the United States. While all of these experiments and practical tests show that petroleum can be used on locomotives without difficulty, and perhaps with some elements of superiority over other kinds of fuel, it cannot be affirmed that it is as yet so economical as to lead to its use in the face of the very grave and unquestioned elements of danger attending it. Coal in the United States is cheap, plentiful, and safe, but on the Caspian sea it is rare and costly. This fact constitutes a sufficient reason why persistent and successful efforts to burn petroleum and residuum on the steam vessels that traverse that sea should have led to its almost exclusive use for steam purposes. The following concise statement explains the method of its use:

An apparatus has been devised for the utilization of petroleum as fuel in steam navigation, and its application for this purpose in central Asia has, it is reported, been attended with results that are considered very satisfactory, such fuel also occupying much less space than the amount of coal necessary to produce a similar effect.

With the old-fashioned boilers in use—with a central opening running longitudinally—no modification, it is stated, is necessary for the employment of the fuel in question. A reservoir containing some hundred pounds' weight of the refuse, "astalki," is furnished with a small tube, bearing another at its extremity, a few inches long and at right angles with the conduit. From this latter it trickles slowly. Close by is the mouth of another tube connected with the boiler. A pan containing tow or wood saturated with astalki is first introduced to heat the water, and on the slightest steam pressure being produced a jet of vapor is thrown upon the dropping bituminous fluid, which is thus converted into spray; a light is applied, and then a roaring deluge of fire inundates the central opening of the boiler. It is a kind of self-acting blow-pipe.

The volume of fire can, it is stated, be controlled by one man, by means of the two stop-cocks, as easily as the flame of an ordinary gas jet. Mention is made of a steamer of 450 tons and 120 horse-power on this principle, 30 pood per hour of astalki being burned to obtain a speed of 13 nautical miles in that time; and as 1 pood is about 33 pounds, and costs on an average about 10 to 12 cents, or about $60 for a twenty hours voyage at full speed.

The use of petroleum in Russia for steam fuel on both locomotives and steam vessels has been very fully discussed by T. Gulichambaroff in the *Gornii Journal* for 1880. He says that—

In the Caucasus the refuse of the distilleries is used as fuel, which in 1874 could be had for nothing. In 1875 the price was 3d. per barrel of 20 poods (720 pounds); in 1876 it rose to 1s., and 1877 to 2s.; in 1879 the price had reached 5s. 3d., while raw petroleum at the same time was 10s. Attention is now being directed to the use of raw petroleum, against which there is a standing prejudice on account of the possibility of explosions. Any liability to explosion is easily removed by exposure to the air for a few days. On the Balachauskoi railroad the locomotives are fired with raw petroleum, which is poured into the tender direct from the springs; yet there has never been an accident. The author has seen burning logs quenched with petroleum without setting it on fire, and spontaneous combustion is impossible, as the oils do not absorb oxygen. At present all the steamers on the Caspian sea use liquid fuel, 4.5 to 4.9 pounds per horse-power; 1,080 pounds of naphtha (petroleum) is found to be equal to 343 cubic feet of oak wood. The use of petroleum by injectors and its freedom from sulphur present great advantages over any other form of fuel. (a)

The action of hydrocarbons at a red heat with steam has been investigated by M. Coquillion. He shows that steam assists the dissociation of the hydrocarbons, producing at the same time a fall of temperature which is added to that produced by the reduction of CO_2 to CO. (b)

As already stated, the use of petroleum for steam fuel is determined by its cost relative to other kinds of fuel. With the low price of petroleum at Baku and the absence of wood and coal on the steppes of Russia and the shores of the Caspian sea, there can be no question that petroleum is the cheapest and best steam fuel to be had in that region. But in the United States the question lies between petroleum and anthracite coal for ocean steamers and bituminous coal on the western rivers. I think no one would now question the ease and efficiency with which petroleum can be burned in several forms of apparatus lately invented, nor can it be denied that it is less bulky than coal and more conveniently handled; but that it is a safe material to use on ocean passenger steamers as compared with coal cannot be maintained. Moreover, the claim that is made that much less stowage is required is not found to hold to any extent against anthracite coal. A ton of anthracite requires 48 cubic feet and a ton of petroleum requires 44 cubic feet. The difference is inconsiderable. As the question is at present stated, I do not look for any considerable increase in the use of petroleum for steam purposes in the United States.

SECTION 3.—PETROLEUM AND ITS PRODUCTS IN THE MANUFACTURE OF IRON.

The natural gas of the oil-wells has been successfully used in the manufacture of iron in the vicinity of Pittsburgh, Pennsylvania. Messrs. Spang, Chalfant & Co., whose works are at Sharpsburg, brought the gas in a 6-inch pipe to their works from wells near Saxonburg, Butler county, a distance of 17 miles. They use it for puddling and heating and for making steam. Messrs. Rogers & Burchfield placed their works at the wells on the Kiskimenitas, a tributary of the Allegheny river. They use it in an ordinary reverberatory furnace by bricking up the bridge and introducing the gas in pipes with a blast. It has been remarked that the quality of the iron is something wonderful; with ordinary gray coke pig-iron sheets for tin-plate equal to those from the best charcoal iron are made at a cost of $50 per ton less.

a Proc. London Inst. Civil Engineers, lxiii, 408.　　　b C. Rendus, No. 19, 1878; C. N., xxxvii. 262.

A large number of processes have been invented and patented for using raw petroleum in the manufacture of iron. Of these the Eames process appears to have been the most successful, and to have had the most satisfactory trial.

At the Laclede iron works, in Saint Louis, experiments have been instituted under what was known as the "Whipple and Dickerson", or "Ambler process". These experiments were unsatisfactory, but in what respect I have not been able to ascertain. Experiments were also made at the Chatham dockyard, in England, which were in many respects highly successful, particularly with reference to the fine quality of iron produced.

The Eames process has been put into practical operation both in Titusville, Pennsylvania, and in Jersey City, opposite New York. Why it has not proven a commercial success I have not been able to learn. Competent judges having an interest in the success of the establishment at Titusville bear testimony to the extraordinarily fine quality of the iron produced from scrap and refuse of the most forbidding character. The process has been made the subject of a most careful and exhaustive examination by Professor Henry Wurtz, of New York, and Professor R. H. Thurston, of the Stevens Institute of Technology, Hoboken, New Jersey. The cut, Fig. 57, represents the apparatus in section. It consists of an ordinary reheating furnace with the "generator" and steam boiler attached. The generator, which is the peculiar feature of the apparatus, is shown at A. It consist of a cast-iron vessel, from the sides of which shelves project alternately. The oil, entering from a reservoir at D, trickles over these shelves, from which it is swept by a jet of steam superheated to incandescence, entering the generator at E from the coil B. The amount of oil required for this furnace, which is capable of working charges of 3,000 pounds and making steam for the rollers besides, is a maximum of 30 gallons or 200 pounds per hour. The trickling oil is met by the jet of steam moving in the opposite direction, and is at once completely vaporized under a pressure of about 10 pounds and is carried into the furnace C. Air enters at F, and, mingling with the mingled vapor and steam, passes through the former bridge at H, and burns within the furnace in a long solid sweep of flame, which escapes from the furnace at I, and returns, after passing beneath the boiler, through the boiler flue to the stack. The old bridge of the furnace is completely bricked up excepting at H, where a space extends across the furnace, closed only by fire-bricks placed on end, and it is found that if this "combustion chamber" has a horizontal thickness of more than 18 inches the fire-bricks are *fused*.

I quote the language of Professor Wurtz's memoir respecting the working of the apparatus described:

It is quite easy to determine with precision with the arrangements at Jersey City the relations of consumption of oil to iron produced, and time, labor, and material occupied in any special case. The oil was fed from a tank, sunk in the ground, which had a horizontal section throughout of 4 feet square. Each inch in depth, therefore, corresponded to 2,304 cubic inches, or closely enough to 10 United States gallons of 231 cubic inches. By gauging with a graduated rod each hour, therefore, the hourly consumption of oil was readily followed up. It was thus determined by me that, starting with a cold furnace and boiler full of cold water, 45 minutes was a maximum time, with oil fed at the rate of 30 gallons per hour, or 22.5 gallons in this time, to bring the whole fire space to a dazzling white heat. Six piles of boiler scrap, averaging 500 pounds, or 3,000 pounds in all, being then introduced, 35 minutes more at the same rate of consumption not only brought the piles to a high welding heat, but raised the steam in the boiler to 90 pounds pressure, being that required to operate the rolls. The time required after the furnace was heated and steam up for each charge of 3,000 pounds averaged at most 80 minutes, and as the brick-work became heated throughout it was apparent that the feed of oil might be somewhat diminished. Thus in a working day of ten hours just seven such charges could be worked off, averaging 2,500 pounds of rolled iron each; total, 8 tons per day of boiler-sheet from one such furnace, with an average consumption, as a maximum, of 30 gallons (200 pounds) of oil per hour, or 300 gallons (2,000 pounds) in all. To this must be added, however, the fuel used under the generator and small supplementary boiler, which together was 500 pounds per day. It is admissible that one generator and one small boiler will operate several furnaces, the inventor says 5; if we say 4, it will diminish the small addendum of cost.

As to working this furnace with coal, it was ascertained from the testimony of the operators that, by keeping up the fire all night, so that a heat could be had at a reasonable time in the morning, the maximum product of finished sheet might be, with superior work, allowing 90 minutes for each heat, 6 tons, with a consumption of at least 5¼ tons of coal = 12,320 pounds, or 2,053 pounds of coal per ton. (a)

I have omitted Professor Wurtz's estimates of comparative cost, as any one interested can readily make them to suit the prices of coal and crude oil in his own locality.

SECTION 4.—STOVES.

During the last few years stoves in great variety have been contrived in which some of the products of petroleum are consumed as fuel. Practically they may be divided into naphtha and kerosene stoves. In reference to the use of the naphtha stoves I have nothing to say, excepting that their manufacture, sale, and use ought to be prohibited by law. I need not repeat here the facts and arguments already brought forward to show why they are dangerous to persons who use them and to the communities in which those persons live. In spite of all that has been written and spoken on this subject, a vast number of them is sold every year. The apparent apathy of the public in reference to this matter is shown by the fact that after the terrible fire in the New York tenement houses in January, 1881, caused by the careless use of gasoline in some sort of plumbers' apparatus, Commissioner Gorman said to a *New York Herald* reporter—

That he had examined the law regarding the use of gasoline, and he found no statute that could prevent its being used as a heating and illuminating agent. Section I, chapter 584, of the laws of 1871 provided that "no refined petroleum, kerosene or other burning fluid shall be used for heating or illuminating purposes in any dwelling, house, store, shop, restaurant, car, coach or other vehicle, which

shall evolve combustible vapor at a temperature below 100° Fahrenheit". Now, had the law not been repealed, it would have prevented plumbers using gasoline for heating purposes. The law, as I have read it to you, was, however, repealed by section 4, chapter 742, of the laws of 1871, which reads "that no refined petroleum, kerosene, coal or similar oil, or product thereof, shall be used for illuminating or heating purposes which shall emit an inflammable vapor at a temperature below 100° F., or shall be kept for sale or stored within the corporate limits of the city of New York". (a)

On the 1st of June following 27 barrels of gasoline lying on the platform of the Consolidated Railroad freight-house in Springfield, Massachusetts, took fire from some accidental cause, and after a part of them were supposed to be extinguished several of the remainder exploded and injured about 40 persons more or less seriously. December 27 following the steamer West Point exploded and burned at West Point, Virginia. Nineteen persons were killed and a number badly injured. Her "cargo was made up of miscellaneous freight, among which were several hundred barrels of oil, sixty of which were *gasoline*". These are some of the gasoline accidents for one year, and yet there is no general legislation to prevent gasoline from being used in lamps and stoves and from being carried as common freight except section 4472 of the Revised Statutes of the United States, quoted on page 236.

The kerosene stoves are being brought to a great degree of perfection, and are found to be very useful. Of the several different manufacturers who are seeking the patronage of the public I am not disposed to select any as making in all respects an article superior to all others. These stoves act best with high-test oil, and are therefore safe. Their healthfulness depends upon the manner in which they are used. It is claimed that one of these stoves with two burners discharges an amount of carbonic acid into the atmosphere of a room equal to the respiration of $2\frac{1}{2}$ persons. I have not examined the merits of this statement; but, assuming the statement to be correct, it is a sufficient reason why the most thorough ventilation should be urged upon those using these stoves. Very few are used under circumstances that admit of the removal of the products of combustion from the apartment, and when one is used in a small room occupied by two persons the contamination of the air amounts to that caused by the constant occupation of the room by from four to five persons. When to this unavoidable source of impure air is added the sulphurous acid and half-burned products of the combustion of poor and cheap oil, the use of petroleum stoves cannot be recommended as conducive to health. Yet they are cheap and convenient, are used by tens of thousands, and their use is increasing.

SECTION 5.—MISCELLANEOUS APPLICATIONS OF PETROLEUM PRODUCTS FOR HEATING PURPOSES.

Petroleum and nearly all of its products and natural gas are used in glass houses for producing high temperatures and flames free from soot and other materials that would injure the glass. At Wheeling, West Virginia, one of the largest glass houses uses benzine for producing the intense heat of the "glory holes", and other houses use natural gas for the same purpose. Throughout the oil regions natural gas is largely consumed in the towns for heating dwellings and culinary purposes. It is used with a large Bunsen burner, from which the flame is projected into an ordinary stove. Another method, and much the best, is to introduce the Bunsen flame into the back of an ordinary portable grate. The grate is filled with fragments of fire-brick, which become bright red in the gas-flame, and radiate as much heat as glowing anthracite, which, in fact, they much resemble.

A novel application of petroleum to the production of motive power has been made successful in Hock's petroleum motor, in which vapor of petroleum is exploded behind the piston of an engine and the expansive force made available as a motor. It claims to possess the following advantages over other similar engines:

1. Perfect safety; neither incompetence nor malice can produce a destructive explosion.
2. No particular attention needs to be given it.
3. The facility with which the engine can be started and stopped, no complex preparations being necessary.
4. Its almost noiseless operation. (b)

At Mosul, Persia, in the valley of the Euphrates, the crude petroleum and maltha from the springs of Hit is used for burning lime, and proves an invaluable fuel in a country nearly destitute of wood.

a New York Herald, January 6, 1881; *Ibid.*, June 1, 1881.   *b Jour. Frank. Inst.* (3), lxviii, 87.

CHAPTER V.—THE USES OF PETROLEUM IN MEDICINE.

SECTION 1.—THE PHYSIOLOGICAL EFFECTS OF PETROLEUM AND ITS PRODUCTS.

Although crude petroleum has been used as a remedial agent from the earliest times, both in the Old World and in the New, I have not met with any recorded attempt at a careful study of its physiological effects. The few notes that I have made in reference to this subject are therefore fragmentary and inconclusive. While in the oil regions I was told several stories relating to the experiences of persons who had breathed natural gas or the vapors of the very volatile fluids that escape from the oil as it flows from the wells. From these several experiences I conclude that the natural gas from the wells intoxicates like laughing gas. Persons leaning over the edge of a well tank experience at first an agreeable sensation, which is followed by unconsciousness. On recovering consciousness, the person is very talkative, exceedingly witty, with a vivid imagination. These effects do not disappear for several days, and are described as resembling somewhat those of a prolonged spree. Death results from the prolonged action of the gas. In March, 1880, a man was found dead at the top of a ladder at the man-hole of a tank. He was supposed to have become asphyxiated while watching the flow of oil into the tank, from breathing the gas which was escaping into the air through the man-hole.

Rhigolene, which is the most volatile fluid ever condensed from petroleum, and the lightest liquid known, is an effective anæsthetic agent, and has been used as a substitute for ether in a few instances. Professor Simpson used naphtha (specific gravity not stated) as an anæsthetic during the extraction of necrosed bones. The insensibility was deep and tranquil, and the breathing was less stertorous than when chloroform is used. Its effect on the heart's action, however, was much greater, the pulse becoming more rapid and fluttering. (a) Dr. French, of the Liverpool, England, board of health, investigated the subject on a memorial of citizens, and reported that petroleum had an offensive odor, but was not injurious to health. (b) Landerer relates a case, but does not say whether the petroleum was crude or refined. It is presumed the material was illuminating oil. A quantity was swallowed, the greater part of which was vomited. It produced a strong, burning sensation in the tongue and throat, both of which became reddened and swollen. The stomach and bowels were also affected with strong symptoms of gastro-enteritis. Both the urine and the sweat smelled strongly of the oil for several days, and the odor was especially strong under the armpits. The patient became very weak, but recovered.

In 1864 M. E. Georges published a memoir upon the physiological effects of petroleum ether, of which the following is a summary:

1. The essence of petroleum acts in a peculiar manner upon the creative faculties (sens génesique), and also under peculiar circumstances upon the temperament.

2. It occasions violent headache with nervous persons.

3. That action appears to be due to a peculiar principle, which may be separated from it, and which acts principally upon the brain and upon the heart.

4. The ether of petroleum can be employed with advantage to produce cold upon the exterior in operations, because it does not produce pain upon the parts where the blood flows. (c) The term petroleum ether evidently designates a substance similar to rhigolene.

The neutral paraffine oils and paraffine itself appear to be without action upon the human system. The extensive use of paraffine for chewing-gum shows it to be without deleterious effects.

Petroleum is generally destructive of animal life, and particularly of insect life. Hildebrant, an African traveler, advises smearing the face and hands with petroleum to protect them from mosquitoes. He also advises the use of petroleum upon horses and cattle as a protection against the deadly Dondorobo gad-fly. By its use natural history collections are also preserved from the invasion of moths and ants in the tropics. (d) Petroleum has been used in France to destroy insects on plants and walls, also on dogs. In the latter case it is applied either before or with soap. An agriculturist of Aube is reported to have said that rats and mice left his cellar when petroleum was stored there, and slugs left a garden that had been watered with the rinsings of petroleum casks. Its use has been recommended upon plants to kill lice, and also to kill mange and scab on dogs and sheep, for which purpose 10 parts of benzine, 5 parts of soap, and 85 parts of water are recommended. It must be used with great caution upon animals. Those who have used it recommend that it be diluted with benzine. The use of crude petroleum and maltha for ridding vines of parasites has already been mentioned, the product of the Albanian springs having been sent to Smyrna and the Levant for that purpose. Moths are destroyed in furniture and garments by immersing them in baths of benzine. One great obstacle, however, to the frequent use of petroleum products is their disagreeable odor, which to many people is particularly offensive.

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a *An. Sci. Dis.*, 1850.   b *Ibid.*, 1864.   c *Ann. du Genie Civil*, 1864, p. 525.   d *Nature*, xviii, 373.

SECTION 2.—PETROLEUM AND ITS PRODUCTS AS THERAPEUTICS.

Crude petroleum has been used as a remedial agent in both external and internal administration. Its use as a liniment dates from a very remote antiquity. In 1839 M. Fournel addressed a letter to the French Academy, in which he discussed the employment of petroleum by the ancients in the treatment of itch. (a) He says :

Pliny (Nat. Hist., Book XXXV, chap. 15), speaking of the petroleum of Agrigentum, that was called Sicilian oil, says: "They make use of it for lamps instead of oil; also for the scab in draught cattle." Before him Vitruvius (Ten Books of Architecture, Book VIII, chap. 3) had mentioned the custom among the Africans of plunging their beasts into the waters of a bituminous spring near Carthage; and after him Solinus (Poly. Hist., chap. II), speaking still of the springs of Agrigentum, says: "It [the oil] is used as a medical ointment in the diseases of draught cattle."

All the authors of the fifteenth, sixteenth, and seventeenth centuries have indicated the same remedy, notably among them François Arioste, who cured men and animals afflicted with itch with the petroleum which he had discovered in 1460 on Mount Libio, in the duchy of Modena. Among many others Agricola also may be cited, who said, in the middle of the sixteenth century, "Cattle and beasts of burden, when smeared with it, are healed of the scab." If I pass to petroleum obtained by distillation, I find that in 1721 Eyrinis obtained from the asphaltic stone of the Val-de-Travers, in the canton of Neuchatel, in Switzerland, an oil, of the efficacy of which for the cure of itch he boasted much, affirming that he had cured more than 30 persons by means of it. (Dissertation upon asphalt or natural cement, etc., pamphlet in 12mo ; Paris, 1721.)

In America crude petroleum has always maintained a high reputation as an external application for rheumatism. The Indians living in the neighborhood of oil-springs used it for that purpose, and the early voyagers learned of them its value. Seneca oil and Barbadoes tar were offered for sale in the United States and Europe many years before petroleum in its present use became an article of commerce. In 1822 the editor of the American Journal of Science acknowledges the receipt from James R. Sample, of Barbadoes, of specimens of Barbadoes green tar, a petroleum of excellent quality, and indurated bitumen or "munjack", and says :

The tar is found very useful in preventing lockjaw, when the first symptoms are attended to, by rubbing the spinal bone from end to end and the muscles of the thigh and arms. When taken internally it is also a powerful sudorific. (b)

Again, in 1833, when writing of the petroleum spring at Cuba, New York, Professor Silliman, sr., says the oil was used by people about that place for sprains and rheumatism, rubbed on. (c)

In recent years refined petroleum has borne a valuable reputation as a hair renewer. It is said to promote the growth and luxuriance of human hair and to stimulate the growth of hair on bald scalps to a wonderful degree. Marvellous as are the tales that are circulated by the press, I know of no authentic case, nor have I observed any notices of such cures in reputable scientific journals.

Throughout the oil regions of Pennsylvania petroleum bears a high reputation as an internal remedy in cases of consumption. The oil of the old American well, under the name of American oil, was sold in Pittsburgh for that purpose at the time when Kier was making his first experiment at distilling petroleum. While in the oil regions I met several persons who testified to having witnessed its beneficial effects either upon their own persons or upon those of near relatives. A Mr. S. stated that his brother-in-law was seriously ill with phthisis, when he commenced taking crude petroleum in teaspoonful doses, which he increased in a year to a tablespoonful. His case experienced a marked improvement, and the tubercles were said by the attending physician to have been healed.

During 1879 the French Bulletin de Therapeutic contained an article in which it was stated that petroleum had been proved very beneficial in chronic bronchitis, and was thought to be so in phthisis. Administered in teaspoonful doses before each meal, the nausea that was first experienced soon disappeared. For administration it had been put up by a Paris pharmacist in capsules containing 25 centigrams of the oil under the name of "huile de Gabion", after an ancient petroleum spring.

Notwithstanding these well-attested facts concerning the therapeutic action of petroleum, it cannot be said to have a recognized status in American pharmacy.

SECTION 3.—PHARMACEUTICAL PREPARATIONS OF PETROLEUM.

Petroleum has been deodorized and purified for administration by filtering. Within a few years a series of compounds has been prepared for homeopathic practice called myro-petroleum compounds. They are prepared by causing to react upon each other fixed oil of mustard, an alkali, and petroleum. The myronic acid of the oil of mustard forms a salt or soap with the alkali in which the petroleum is dissolved. There are four primary preparations, viz :

1. Myro-petroleum—album.
    Refined petroleum.
    Mustard oil.
    Alkali.

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a C. Rendus, ix, 217.   b Am. Jour. Sci. (1), v, 406.   c Ibid. (1), xxiii, 99.

2. Myro-petroleum—nigrum.
>   Crude petroleum.
>   Mustard oil.
>   Alkali.
3. Myro-petroleum soap.
>   A mustard-oil soap containing paraffine.   The claim is made that paraffine is saponified.
4. Glycero-petroleum.
>   Which it is claimed is a petroleum *glycerine.*

The first three preparations are, no doubt, produced as claimed, and their merits as therapeutic agents rest on careful tests, not upon opinion. The claims that are set up, however, for these preparations—that paraffine is saponified and that glycerine is prepared from petroleum—show that the persons making such claims have no clear idea of the chemical constitution of either petroleum or the saponifiable fats. Paraffine was so named from being found destitute of affinity, and acids and alkalies have no more action upon pure paraffine than upon a piece of India rubber, and no substance resembling glycerine has thus far been obtained from petroleum or any of its products. They are all, however, including paraffine, soluble in soaps; hence soaps may be produced containing paraffine or petroleum, but glycerine cannot be obtained from petroleum. About 15 per cent. of paraffine can be incorporated with soap. These soaps are found very valuable in hospital practice for washing malignant ulcers and inflamed mucus surfaces. It is, however, as a material forming the basis of ointments that the preparations of petroleum have obtained their strong hold upon the medical profession. The preparations cosmoline, vaseline, petrolina, etc., which are all essentially the same thing, have now a permanent place in the materia medica.

As early as 1861 C. T. Carney, of Boston, substituted paraffine for wax, spermaceti, and almond oil in cerates, and exhibited specimens at the meeting of the Pharmaceutical Association that year. He remarked :

> An ointment made in this way would, in my judgment, be very permanent and keep a long time without becoming rancid or ropy.

White wax in small amount rendered the ointment more tenacious. (*a*) It was not until the discovery and preparation of so-called amorphous paraffine that a material was furnished to pharmaceutists that was destined to supplant the old preparations. I have made no attempt to adjust the conflicting claims of those who manufacture this preparation under different names. I prefer to leave that to the subtle administration of patent law. It is sufficient for my purpose that somebody discovered that when a petroleum residue obtained by evaporating the oil *in vacuo*, or by any other means that will prevent its destructive distillation, is filtered through animal charcoal, an amber-colored, nearly odorless material is obtained of the consistence of paste at ordinary temperatures. One man called it cosmoline, another vaseline, and others have given it other names. Whatever named, amorphous paraffine is rapidly becoming the ointment of the world. It is prepared by the manufacturers either plain or scented with rose or some other perfume for the retail trade, and is also prepared in bulk for the apothecaries.

At the meeting of pharmacists, held in 1880, for the revision of the United States Pharmacopœia, the superior claims of this material over all other preparations as a basis for ointments were acknowledged, and the necessity for its recognition as an officinal preparation of the pharmacopœia was conceded. Some difficulty was experienced in preparing a formula for a substance the origin of which was hidden behind the mysterious veil of conflicting patent rights. On the other hand, the profession was justly cautious in recognizing a name that might designate one thing to-day and another to-morrow. Finally *Unguentum Paraffini* obtained a name and place in the Pharmacopœia. Some difficulty has been experienced in establishing a proper melting point for the preparation. The merits of this question are fully set forth in the following paper, prepared by Dr. Charles Rice, of the Bellevue hospital, New York, and read at the last (1881) meeting of the American Pharmaceutical Association :

> "What melting point is most desirable for petroleum ointment ?" * * * Our present as well as former pharmacopœias contain two principal classes of unctuous substances intended for external application; one of these of the class of cerates, and the other that of ointments. These have generally been understood to have two entirely different functions, at least in the majority of cases, and for this reason they have been carefully kept apart, although they overlap each other in a few instances. A cerate, as the name already implies, is a "waxy" ointment, that is, an ointment stiffened with wax, for the purpose of raising its melting point. An ointment is intended chiefly for "inunction", and for this reason should possess a melting point but little above that of the temperature of the body. A cerate, on the other hand, is rather intended as a dressing, to be spread on lint, linen, or muslin, and to be applied to the injured surface.
>
> These well-known distinctions furnish the clue to the solution of the question, at least from the standpoint of theory, and also from the standpoint of the physician. The writer has had an opportunity during the past year of learning the views and opinions of a considerable number of practitioners on this subject, and he only regrets that he cannot quote their statements and reports, which were made for another purpose than the drafting of the present paper in full, and with their names attached; but he is at liberty to state that most of them, and among them the foremost dumatologists, pronounce the melting points of several of the commercial petroleum ointments to be altogether too low.
>
> During the heat of summer particularly, and in the warmer sections of our country even in other seasons of the year, an ointment should not have a melting point below about 40° C. or 104° F., and as it is easier to soften an ointment by heat than to stiffen it by cold, it appears preferable to select a uniform melting point for the year round, based on the requirements of the average summer temperature.

Petroleum ointment is principally desired by practitioners as a perfectly *bland, neutral,* and *inactive* base for suspending therein various topical remedies. Naturally, this very property of blandness and neutrality will in many cases alone produce curative effects, because it will permit the natural healing process to proceed normally and uninterruptedly, provided the injured part is thoroughly covered so as to exclude the air.

From the opinion of most of the practitioners whose views have been solicited or tendered two petroleum ointments of different melting points are chiefly desirable. One of these, which could take the place of lard or ointment or other low-melting unctuous compound, should have a melting point of 40° C. or 104° F. And the other, which could take the place of cerate or of corresponding compound of higher melting point, should have a temperature of about 46° C. or 115° F.

The preceding would be an answer to the query from the standpoint of the physicians. But there is another feature connected with the query which cannot well be separated from it, though it is not expressed in words. In fact, the question might as well have been formulated thus:

What is the most desirable melting point to be recognized by the next pharmacopœia for petroleum ointment?

While the pharmacist acknowledges the correctness of the distinction between ointment and cerates, and will doubtless agree with the opinion of the physician that there should be, both a soft and a firm petroleum ointment, according to the purpose for which it is to be used, he will, on the other hand, most probably deprecate the introduction of more than *one* kind of simple petroleum ointment into the pharmacopœia, because a multiplicity of them will surely result in confusion, both on the part of prescribers and dispensers, and besides, because the likelihood of the pharmacopœial requirements being observed, will diminish in proportion to the number of grades recognized, since it is out of question for the retail pharmacist to prepare the article himself. Hence, from the standpoint of the pharmacist, it will be safest, at least with our present knowledge and experience, to recommend the official recognition of that petroleum ointment only which has the *lowest* melting point declared suitable by competent medical authority. And this melting point is 40° C. or 104° F. Any higher melting point can be easily obtained by incorporating with the petroleum ointment more or less *yellow wax*, and the exact consistence and melting point of the product will, therefore, be more easily within the personal control of the pharmacist than if he were compelled to rely upon the alleged melting point of a manufactured product.

The addition of *yellow wax* to petroleum ointment has long been known to yield a perfectly homogeneous and satisfactory product. Nor does it introduce into the mixture any source of deterioration, at least for any reasonable period of time, since it has been shown that the mixture remains a long while free from all trace of rancidity, particularly if the petroleum ointment itself was sweet and fresh.

It has been said above that pharmacists, as a rule, will probably prefer only *one* officinal petroleum ointment, and this supposition will probably be confirmed should any discussion of this paper take place after being read. But it is also approved by quite a number of physicians with whom the subject has been discussed, and to whom the difficulties attending the recognition of several grades have been pointed out. But, so far as the writer is aware, those who advocate the introduction of only one petroleum ointment, whether pharmacists or physicians, do not deny the correctness of the statement of the other side, that several grades of petroleum ointment of different melting points are very desirable. They only wish to point out that the *official* recognition of more than *one* kind would, by no means, be a guarantee that the other products could even be at all times procured in the market when required, or would be furnished if ordered. And as it is certain that the pharmacist can furnish to the physician equally satisfactory products of *controllable* and *known* melting points, if such are required, by the method above indicated, it is hoped that the two professions will come to the harmonious conclusion to recognize, in the forthcoming new pharmacopœia, only *one* petroleum ointment having a melting point 40° C. or 104° F. (*a*)

The merits of these preparations have met with a very cordial recognition in Europe, and frequent mention is made of them in foreign journals under the names of either cosmoline or vaseline. The following notice from an English journal presents many facts of general interest in relation to the substance and the varied uses to which the apothecary can apply it. It is presented in preference to others for the sole reason that it was convenient of access, and well represents the appreciative consideration which has been extended to "petroleum ointment" on the other side of the Atlantic:

AN ENGLISH VIEW OF VASELINE. (*b*)

BY W. H. SYMONS, F. R. M. S., F. C. S.

Although petroleum in some form or other has been in use for two thousand years (Herodotus, born B. C. 484, is the first writer who distinctly refers to it), petroleum jelly or vaseline has only been known during the last few years, and is said to have been discovered by Mr. R. A. Cheesebrough, of the Cheesebrough Manufacturing Company. I have been unable to find any authentic account of the manufacturing process, but according to the pamphlet which I have on the table, and which most of you have doubtless read, it is the residue from the distillation of petroleum purified by an elaborate system of filtration, known only to the company, or at least so says the pamphlet. This secrecy of its manufacture is one of the greatest drawbacks to its usefulness and official recognition.

Vaseline was the subject of an original paper read by Mr. J. Moss at the meeting of the Pharmaceutical Society, on February 2, 1876. He describes it as a pale yellow, translucent, slightly fluorescent, semi-solid, melting at 37° C. and having a specific gravity of 840 at 54° C. It is insoluble in water, slightly soluble in alcohol, freely so in ether, and miscible in all proportions with fixed and volatile oils. It is not acted upon by hydrochloric acid or solution of potash, and has all the other characteristics of a mixture of paraffines; an ultimate organic analysis made by him gave 97.54 per cent. of hydrocarbons.

Under the microscope, vaseline, in common with most other fats, is found to contain numerous small acicular crystals, doubtless consisting of a paraffine of higher melting point than the mass, but these do not in any way interfere with its usefulness, because of their extreme minuteness and easy fusibility.

Vaseline may be kept indefinitely without becoming rancid; this is its chief characteristic, and together with its indifference to chemicals and its readiness to take any perfume is sufficient to recommend it for pharmaceutical and toilet purposes in place of the fats generally used. (*c*)

If vaseline be considered too thin it may be thickened to any extent with paraffine wax. I have found one to seven a good basis for general use, or one in ten would answer for most purposes; but to obtain anything like smoothness in the mixture it must be thoroughly

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a Proc. Am. Pharm. Ass., 1881; *Oil and Drug News,* September 6, 1881.

b A paper read before the School of Pharmacy Student Association, London.

c One improvement seems to me to be possible, and that is the isolation of single paraffines, of various melting points, one suitable as a basis for liniments, another for ointments, in place of the mixture of paraffines sold as vaseline. (The objections to this multiplicity of preparations have been presented by Dr. Rice.—S. F. P.)

beaten while cooling. Vaseline alone being used for making such ointments as that of ammoniated mercury, or for diluting mercurial or the nitrate of mercury ointments, a partial separation takes place on keeping; but if a mixture of paraffine wax and vaseline be used no such separation occurs.

With regard to the preparations of the pharmacopœia, in which vaseline has been suggested as a substitute for the basis in present use, first and foremost I must mention the nitrate of mercury ointment. Squire states that this can be prepared from white vaseline by substituting it for the lard and oil in the official formula. I tried the experiment on half a pound of white vaseline, using the B. P. quantities of nitric acid and mercury and a temperature rising to 214° F., but it was a decided failure. I could obtain nothing but a mechanical mixture, the vaseline being changed in color from white to pale yellow and the acid solution continually weeping out, and nearly all of it could be separated by pressure. It may be that failure arose from lack of manipulative skill on my part, but I have generally been able to get fair results with the B. P. process. I have on the table a specimen of citrine ointment, prepared from a mixture of white wax and vaseline and about the same quantity of mercury, but rather less nitric acid; this specimen is about eighteen months old, and is as good as when first made. As far as my experience goes, vaseline is not suitable for making citrine ointment of full strength, but it certainly is useful for its dilution. Here is some fresh official ointment, and also some recently diluted with vaseline. I likewise have a specimen which I prepared two years ago; its color is still good. I found that the vaseline had partly separated from it, and in future shall make it with one-eighth paraffine wax.

The next troublesome ointment, I think, is that of red oxide of mercury. I have here a sample of the official ointment, which has been kept for over two years, and is now certainly an unsightly preparation; also some made with prepared lard, quite as bad. Benzoated lard seems to have answered very much better, but still more successful is the mixture of castor oil and beeswax, suggested some years ago in the *Pharmaceutical Journal.* Vaseline, however, will take the palm for more elegant appearance, and it will keep any length of time unaltered.

Compound lead ointment has been spoken of as very liable to change. I have some here made from the official formula which has been kept over a year, and also some made with vaseline eighteen months ago; likewise a sample of zinc ointment. The official ointments, although only a few months old, are quite rancid; but the samples made with vaseline show no alteration after being kept eighteen months.

Mercurial ointment is also very advantageously made with vaseline and wax, instead of with rancid fat, as is usually the case. Under the microscope, samples of both ointments exhibit globules of mercury of about equal size.

Iodine is soluble in about twenty times its weight of vaseline; therefore vaseline is very suitable as a basis for iodine ointment. I am not aware of any action occurring between iodine and the paraffines, although action does take place with chlorine and bromine under favorable circumstances. I prepared some a few days ago of B. P. strength, but without any iodide of potassium.

The crowning success for vaseline is in the preparation of cold cream, and if this were the only compound in which it could be used with advantage its mission would, I think, be fully accomplished. I have made my cold cream for some time with white vaseline, and have found a very marked increase in my sale for that article. I have kept a sample freely exposed to air in a warm place for some months without any alteration, except loss of water. I make it by dissolving ℥ ij. of white wax in 1 pound of white vaseline by heat, adding ℨ iss. of borax dissolved in ℥ ix. of water, and perfume with ℨ ss. of oils, stirring until nearly cold and then pouring into pots.

Vaseline, with or without paraffine wax, is undoubtedly the best basis for pomades, and only requires one-half the quantity of perfume common fats do.

Vaseline has been suggested for internal administration, but it is not the province of the pharmacist to discuss the relative merits or demerits of any therapeutic agent; it behooves him, however, to study the best method of exhibiting it, and to bring it to the notice of the physician.

The Cheesebrough Company prepare vaseline in the form of pastilles, which they say contain 33 per cent. of vaseline, with a like quantity of sugar and gum; these they flavor with wintergreen oil, which is very much appreciated by our cousins across the Atlantic, but not so much so on this side.

Vaseline can be emulsified with the usual agents. The emulsion made with gum acacia is tolerably permanent, also that with yolk of egg. If for external application the vaseline can be mixed with one-eighth its weight of white wax and then emulsified with borax or any alkali. The sample on the table was prepared by triturating ℨ ij. of white vaseline and gr. xv. of white wax with ℨ xiv. of water containing gr. xv. of borax in solution.

I do not look upon vaseline as a nostrum, or I certainly should not have brought it before your notice. It is true we have not yet been let into all of the details of its manufacture, but it may be that such disclosure is not far distant. Because the manufacture of Duncan's chloroform is kept a profound secret among the partners of the firm, has that prevented the medical profession from insisting upon that particular preparation as an anæsthetic? If medical men do not hesitate, when it falls in with the interest of the profession and the public, to recommend a particular preparation of a particular firm to the exclusion of all others, I do not see why chemists should consider it *infra dig.* to recommend and use such an elegant and useful article as vaseline. One trouble looms in the far distance—will the supply of vaseline last as long as the demand for it? Coal may be replaced, and heat and light obtained from electricity by unknown means; but how shall we find a substitute for vaseline, unless, indeed, we be able to make it from its so-called elements? The supply of petroleum does not, however, seem to show any signs of decrease at present. Sources known two thousand years ago still yield bountifully, and if the American supplies prove as permanently productive as those of the Old World we may leave this question for the present. (a)

Benzine has been used as a solvent for certain oleo-resins. (b) It has been used successfully in the preparation of atropine, santonine, veratrine, delphine, strychnine, brucine, cantharadine, quinine, cinchonine, narcotine, aconitine, and coumarine.

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a *London Pharmaceutical Journal,* 1881.　　　b *Proc. Am. Pharm. Ass.,* 1873, p. 592.